The Journal of Thoracic Surgery

VOL. 6 FEBRUARY, 1937 NO. 3

Original Communications

AN EXPERIMENTAL STUDY OF SOME OF THE PHYSIOLOGIC CHANGES FOLLOWING TOTAL PNEUMONECTOMY*

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IN THE lung as in any other organ, there exists a large functional reserve which may be called into play by increasing demands upon the respiration. This intrinsic lung function possesses a power of prompt adaptation to the changing demands made upon it. Since this function is so intimately associated with the heart, it is a question whether it would not be more accurate to speak of these changes as changes in cardiorespiratory reserve.

From the time of Biondi's[1] early experiments (1884), it has been known that animals could survive the removal of the lung on one side. It was, however, not until the work of Heuer and Andrus[2] in 1922 that any attempt was made to study the compensatory adjustments of the organism to pneumonectomy. With their animals under *resting* conditions they noted following pneumonectomy:

1. An increase in alveolar carbon dioxide lasting for thirty days.
2. A fall in alveolar oxygen returning to its preoperative level in twenty-eight to sixty-six days.
3. A slight increase in the blood carbon dioxide falling to normal by the twenty-fifth day.
4. A marked fall in the blood oxygen content up to the eleventh day, returning to normal by the twenty-fifth to thirtieth day.

The following year Andrus[3] reported a 42 per cent decrease of the *total* lung volume immediately following pneumonectomy with a re-

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Read before the Nineteenth Annual Meeting of the American Association for Thoracic Surgery at Rochester, Minnesota, May 4, 5, 6, 1936.

turn to the preoperative level in twenty to twenty-six days. He also noted a transient increase in the pulse rate and the blood flow through the remaining lung, which persisted for ten days and later fell to slightly below the preoperative level.

Wiggers[4] (1921), Underhill[5] (1921), Haggart and Walker[6] (1923) measured the increase in the pressure in the pulmonary artery produced by the occlusion of one of its main branches. Scarff[7] (1926) reported an immediate increase (30 to 50 per cent) in the systolic pulmonary arterial pressure following pneumonectomy, returning to the preoperative level in from seven to twenty-one days. Churchill[8] (1929) demonstrated that the burden thrown on the lung by a sudden increase in blood flow is not entirely borne by the increase in pulmonary ventilation, but is in part compensated for by an increase in the area of functional diffusing surface. This may be brought about by the opening up of reserve capillaries according to the concept of Wearn.[9] Drastich[10] and his coworkers (1934) reported that reduction in active pulmonary tissue by 50 per cent does not embarrass the organism when engaged in moderate exercise (running on the level for thirty minutes), but that more strenuous exercise, such as swimming, results in the formation of more fixed acid than normal.

EXPERIMENTAL STUDY

In the course of a previous experimental study of the factors responsible for the healing of the bronchial stump following pneumonectomy, it was noted that several of the animals in the paddock which were the most pugnacious and belligerent, were pneumonectomized animals. In consequence, thereof, the following study was undertaken to evaluate, in accurate physiologic terms, the degree of cardiorespiratory impairment at various intervals following pneumonectomy. The study was to be carried on to that point where the animals showed no further compensatory change. In short, an attempt was to be made to assay the degree to which the animals could in time achieve a functional adaptation to the anatomic removal of approximately 50 per cent of their pulmonary tissue.

Since it is only under conditions of increased oxygen demand by the tissues that the efficiency of the cardiorespiratory system can be tested, it was decided to study the physiologic response in a series of trained young healthy dogs to varied amounts of moderate strain. Studies were made of the alteration in pulse, respiration, temperature; blood gas changes in both arterial and venous bloods and oxygen debt during treadmill runs of one, one and a half, and two hours. Tracings were made of the respiratory dynamics at the resting level; the subtidal lung capacity was determined by the method of Christie, and the blood hemoglobin measured in terms of grams hemoglobin per 100 c.c. In addition, the animals were submitted to absolute strain by means of the anoxemia test (to be described later), and the critical level of the oxygen tension of the inspired air was determined. In short, these animals were to be their own controls; any change following pneumonectomy could be compared with preoperative values, thereby eliminating the possible error of individual variations of the controls.

The animals were then pneumonectomized, the left lung being removed by the method described by one of the authors.[11] An interval of two months was allowed

to elapse in order to assure the recovery of the animals to the point that they could bear up under the rigors of the tests. The above observations were then repeated at monthly intervals. The degree of change was noted, and the results were correlated with the simultaneous change in subtidal lung volume, rate and depth of respiration, hemoglobin, etc.

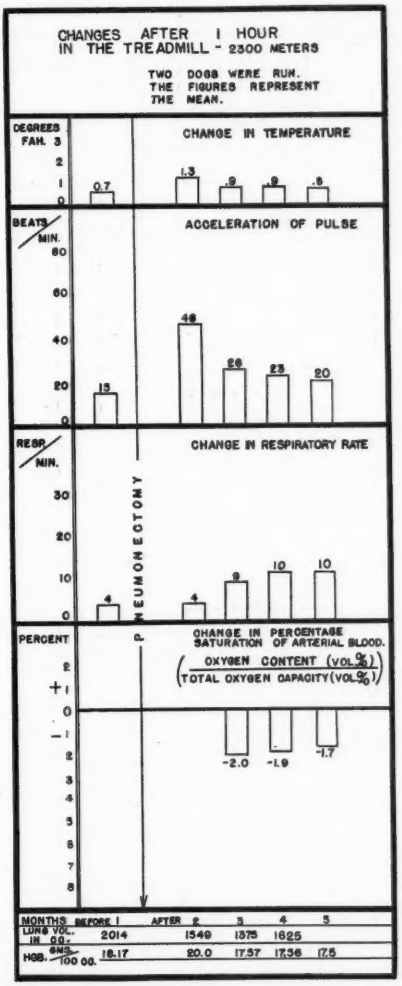

Chart 1.

I. *Moderate Strain Experiments.*—In all the exercise experiments, the same routine was followed. The pulse, the respiration, and the temperature were determined with the animal at rest. The bloods were then drawn and introduced under oil into vials containing potassium oxalate crystals. The arterial blood was obtained by femoral artery puncture and the venous blood drawn from the saphenous vein. The animal (previously trained) was then placed on the motor driven treadmill and

TABLE I

ONE HOUR IN TREADMILL. DOG NO. 543

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY							
	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	CHANGE IN O_2 SAT.	BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	101.8	102.4	122	140	42	30	O_2 24.9 CO_2 33.1	22.2 40.8	26.5	23.6	0.0%	O_2 17.7 CO_2 34.4	20.5 34.4	18.58	1050	5.01%
Pneumonectomy																
2 months after pneumonectomy	101.6	103.0	90	148	30	34	O_2 27.4 CO_2 32.0	30.6 35.0	28.5	31.0	2.6%	O_2 CO_2	22.2 35.6	21.3	970	15.9%
3 months after pneumonectomy	102.0	102.8	106	128	20	28	O_2 22.3 CO_2 37.4	20.4 36.5	25.3	23.3	−0.6%	O_2 17.6 CO_2 37.4	20.2 36.4	18.5	1049	14.0%
4 months after pneumonectomy	102.0	102.6		88	120	26	O_2 23.9 CO_2 35.7	23.3 37.9	24.8	24.7	−2.1%	O_2 14.6 CO_2 40.7	13.7 41.8	17.0	1060	9.4%
5 months after pneumonectomy																7.6%

TABLE II

ONE HOUR IN TREADMILL. DOG NO. 548

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY							
	BEFORE EXER.	EXER. AFTER	BEFORE EXER.	EXER. AFTER	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	CHANGE IN O_2 SAT.	BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	101.0	101.8	88	100	16	20	O_2 24.2 CO_2 33.0	22.0 40.0	25.8	23.6	-0.7%	O_2 17.5 CO_2 34.2	19.5	17.76	3023	5.4%
Pneumonectomy																
2 months after pneumonectomy	101.4	102.6	88	120	16	20	O_2 25.3 CO_2 40.7	24.3 40.5	25.6	—	—	O_2 16.7 CO_2 44.0	22.7 39.2	18.73	2128	10.8%
3 months after pneumonectomy	102.2	103.2	90	120	20	30	O_2 21.4 CO_2 44.5	20.9 41.9	22.8	23.1	-3.4%	O_2 18.5 CO_2 45.9	17.1 41.7	16.64	1700	13.6%
4 months after pneumonectomy	102.2	103.4	96	110	20	34	O_2 23.2 CO_2 42.2	22.5 39.4	24.6	24.3	-1.7%	O_2 20.7 CO_2 44.1		18.13	2211	9.2%
5 months after pneumonectomy	102.0	102.8	100	120	20	30	O_2 23.2 CO_2 42.2	22.5 39.4	24.6	24.3		O_2 20.7 CO_2 44.1	24.9 38.8	18.1		8.3%

run for a given period of time, i.e., traversing at a fast walk of 2,300 meters in the one hour run, 3,450 meters in the one and a half hour run or 4,600 meters in the two hour run. At the end of the run, the bloods were drawn, pulse, respiration and temperature changes noted. Both arterial and venous bloods were obtained within one to two minutes following the completion of the run. The oxygen and carbon

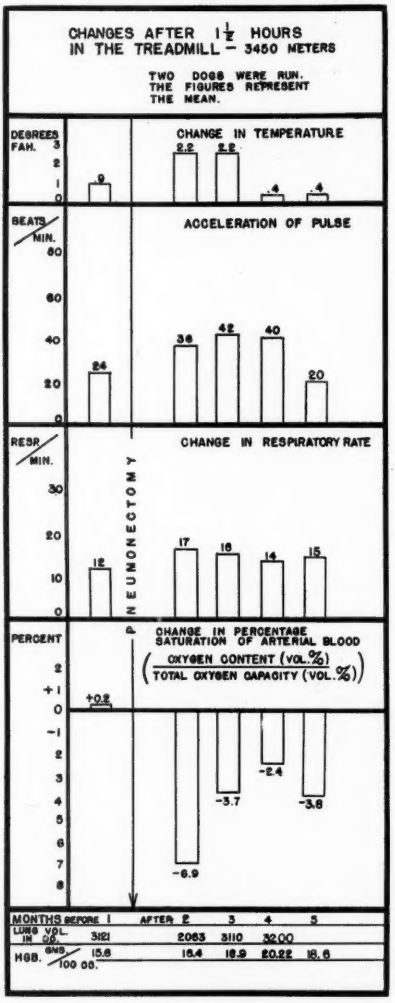

Chart 2.

dioxide determinations were made on both the arterial and the venous bloods on a Van Slyke and Neill manometric blood gas apparatus. The oxygen capacity of the arterial bloods both before and after the runs was then determined and the percentage of change in the saturation of the arterial blood during the run noted. It is felt as a result of these findings that the changes in the oxygen saturation of the arterial bloods under condition of strain are an index of the integration of the three main

TABLE III

ONE AND ONE-HALF HOURS IN TREADMILL. DOG NO. 554

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY		CHANGE IN O_2 SAT.					
	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.		BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	102.2	102.8	72	96	16	24	O_2 19.2 CO_2 33.5	17.3 33.4	21.5	19.4	0	O_2 16.9 CO_2 41.5	15.8 34.0	13.83	3650	5.6%
Pneumonectomy																
2 months after pneumonectomy	103.6	104.2	100	140	20	40	O_2 22.0 CO_2 40.8	17.8 40.0	23.2	20.4	6.8%	O_2 17.7 CO_2 50.9	18.5 37.6	16.04	2450	14.4%
3 months after pneumonectomy	103.4	104.6	98	140	24	42	O_2 18.6 CO_2 50.9	18.9 37.6	20.3	21.3	3.7%	O_2 15.8 CO_2 44.4	14.0 52.3	14.77	3384	12.6%
4 months after pneumonectomy	Dog died of distempter															

TABLE IV

ONE AND ONE-HALF HOURS IN TREADMILL. DOG NO. 568

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY							
	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	CHANGE IN O_2 SAT.	BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	101.0	102.0	100	124	20	36	O_2 19.15 CO_2 33.0	17.3 32.56	21.52	19.4	+0.2%	O_2 11.96 CO_2 43.5	13.96 35.8	15.6	3121	5.02%
Pneumonectomy																
2 months after pneumonectomy	99.4	102.8	112	150	36	50	O_2 21.7 CO_2 44.3	20.6 32.2	22.5	23.0	-6.9%	O_2 15.0 CO_2 46.7	16.4 38.2	16.4	2163	10.2%
3 months after pneumonectomy	99.8	102.8	110	152	30	44	O_2 25.0 CO_2 33.4	21.6 32.7	26.1	22.6	-4.0%	O_2 18.1 CO_2 36.1	18.3 34.2	18.9	3109	14.3%
4 months after pneumonectomy	101.4	101.8	120	160	36	50	O_2 25.4 CO_2 31.4	25.4 33.8	27.4	28.1	-2.4%	O_2 17.1 CO_2 36.7	23.3 45.2	20.22	3217	9.0%
5 months after pneumonectomy	100.8	101.2	100	120	32	54	O_2 24.4 CO_2	22.8	25.4	24.7	-3.8%	O_2 CO_2		18.6		7.7%

factors in the respiratory system; namely, the effectiveness of ventilation, diffusion of gases, and perfusion of the lungs. The following are the results obtained:

(A) One Hour in the Treadmill (2,300 meters): The normal prepneumonectomy animals after one hour on the treadmill showed a slight rise in temperature, pulse

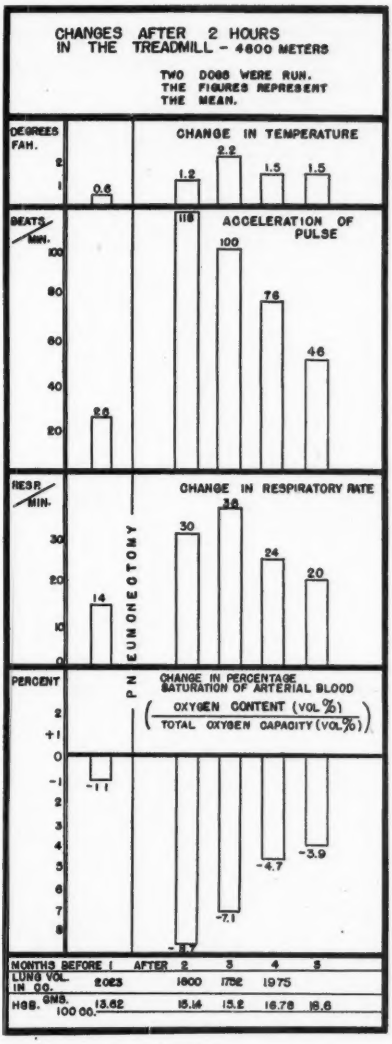

Chart 3.

and respiration, but did not show any decrease in the saturation of the arterial blood. Two months following pneumonectomy, the rise in temperature was practically doubled, and the pulse acceleration was tripled. The respirations were increased but slightly, and there was no decrease in the saturation of the arterial blood. On the succeeding runs, there was a tendency for the pulse and the temperature rise to

TABLE V

ONE AND THREE-FOURTH HOURS IN TREADMILL. DOG NO. 549

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY							
	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	CHANGE IN O_2 SAT.	BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	103.2	100.6	100	100	22	30	O_2 18.2 CO_2 37.6	17.6 36.5	18.82	18.55	1.7%	O_2 17.65 CO_2 32.9	15.0 36.9	13.67	3600	5.62%
Pneumonectomy																
2 months after pneumonectomy	102.2	102.8	110	130	20	20	O_2 17.3 CO_2 37.1	18.2 31.4	17.3	19.3	5.7%	O_2 13.7 CO_2 39.4	16.7 47.5	14.03	2135	13.3%
3 months after pneumonectomy	103.0	103.6	110	130	24	40	O_2 21.7 CO_2 35.6	20.3 40.1	23.3			O_2 17.8 CO_2 39.6	20.3 38.7	17.01	20.46	10.3%
4 months after pneumonectomy	103.0	104.2	104	104	24	30	O_2 22.3 CO_2 36.8	30.2 35.1	23.3	22.0	3.9%	O_2 22.3 CO_2 36.8	20.2 35.1	17.01	3900	7.2%
5 months after pneumonectomy	102.6	103.0	110	120	24	30	O_2 22.2 CO_2	21.8	24.0					18.6		7.5%

TABLE VI

TWO HOURS IN TREADMILL. DOG NO. 564

	TEMP.		PULSE		RESPIRATION		ARTERIAL BLOOD					VENOUS BLOOD		HEMOGLOBIN	LUNG VOLUME	ANOXEMIA TEST
									O_2 CAPACITY							
	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	BEFORE EXER.	AFTER EXER.	FALL IN PER CENT SAT.	BEFORE EXER.	AFTER EXER.			
Before pneumonectomy	101.0	101.6	94	120	20	34	O_2 18.2 CO_2 37.6	17.6 36.5	18.82	18.55	-1.1%	O_2 17.54 CO_2 32.9	15.0 36.4	13.62	2025	7.0%
Pneumonectomy																
2 months after pneumonectomy	101.4	102.6	92	210	20	50	O_2 20.3 CO_2 35.7	17.9 32.8	20.3	19.6	-8.7%	O_2 18.5 CO_2	17.2 33.1	15.14	1600	12.5%
3 months after pneumonectomy	102.4	103.6	100	200	24	60	O_2 19.4 CO_2 33.1	18.6 34.2	21.0	21.8	-7.1%	O_2 15.5 CO_2 32.0	19.4 33.0	15.2	1752	12.5%
4 months after pneumonectomy	102.8	104.2	120	196	20	44	O_2 22.3 CO_2 33.7	20.5 29.7	23	22.2	-4.7%	O_2 20.1 CO_2 33.1	16.7 34.7	16.78	2484	9.5%

return toward the preoperative levels, the animals showing, however, a slightly greater increase in respiratory rate and a tendency toward slight decrease in the saturation of the arterial blood. For details see Chart 1 and Tables I and II.

(B) One and a Half Hour in Treadmill (3,450 meters): The normal (prepneumonectomy) animals showed a moderate increase in temperature, pulse, and respirations following the run of 3,450 meters, but they did not show any decrease in the saturation of the arterial blood. Two months following pneumonectomy, after exercise they showed a more marked elevation of temperature, pulse and respiration, and there was a marked decrease in the saturation of the arterial blood. On succeeding runs, the pulse tended to remain elevated, although the respiratory rate was diminished and the degree of unsaturation was markedly decreased. Clinically these animals showed much more embarrassment postpneumonectomy than did the one-hour group. Review of the data on Chart 2 and Tables III and IV reveals the cause.

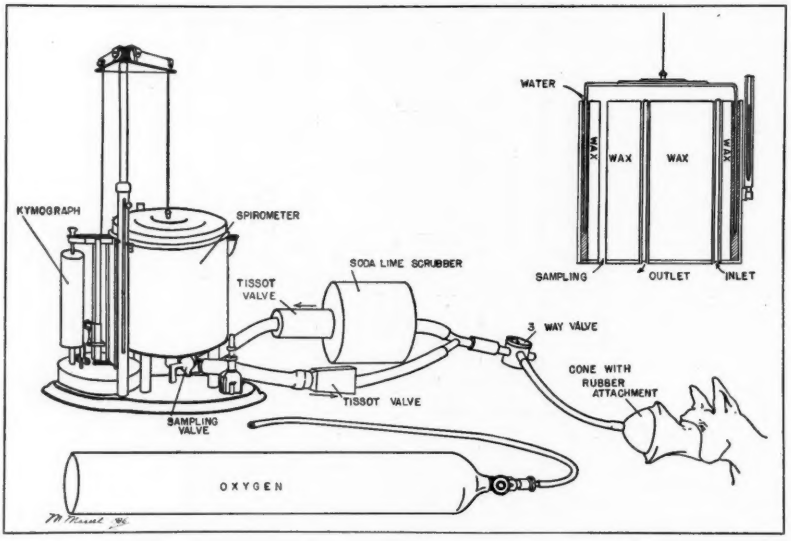

Fig. 1.

(C) Two Hours in Treadmill (4,600 meters): The normal prepneumonectomy animals showed, as a result of their run, a moderate increase in temperature, pulse, and respirations along with a slight decrease in the saturation of the arterial blood. Following pneumonectomy, the exercised animals showed a very alarming elevation of the pulse associated with a very marked decrease in the saturation of the arterial blood, the arterial blood being almost venous in character. The animals when taken off the treadmill were in a very alarming condition, being almost completely exhausted. Three months following pneumonectomy, the condition of the animals was less alarming after the run. Four months postpneumonectomy, the animals although showing a considerable elevation of pulse, respiration and temperature did not, after the run, show any considerable distress, but there was a decrease in the degree of unsaturation of the arterial blood. For details, see Chart 3 and Tables V and VI.

II. *Absolute Strain as Measured by the Anoxemia Test.*—In 1878, Paul Bert[12] in studying the effects of lowered oxygen pressure noted that sparrows died when the

oxygen dropped to 3.5 per cent. Haldane[13] has shown that in human beings when a small quantity (6,000 c.c.) of air is rebreathed continuously up to the verge of loss of consciousness, the carbon dioxide being absorbed, the inspired air contains 4.8 per cent oxygen and the alveolar air 0.7 per cent oxygen. With the onset of acute anoxemia there is noted first an increase in the respiratory and circulatory rate along with a great rise in blood pressure. With further increase in the degree of anoxemia, the heartbeats, like the respirations, become more and more feeble. According to Haldane, in acute anoxemia the respiratory center becomes very susceptible to fatigue and the respirations seem almost always to fail before the heart fails.

On the basis of these facts, it seemed possible to devise a test which would put the ultimate degree of strain on the cardiorespiratory unit and still would spare the animal. The animals were made to breathe room air in a closed system (see Fig. 1), the carbon dioxide being removed and the oxygen gradually being consumed by the animal to a certain critical point. This end-point was found to be quite definite and to be recognized by the following phenomena: loss of consciousness with wide dila-

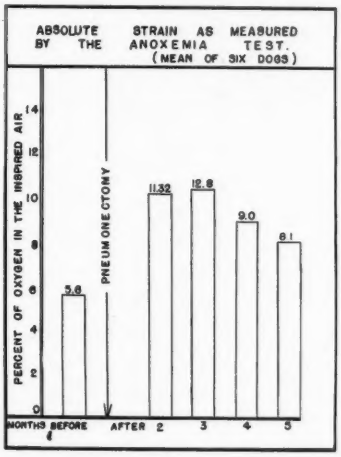

Chart 4.

tation of the pupils, loss of both urinary and rectal sphincter control, cessation of respirations (except for occasional gasps) along with complete loss of all motor tone. The loss of tonus of the rectus muscle, along with relaxation of the muscles in the extremities, was found to be the most clear-cut end-point. At this point, although respiratory movements had practically ceased, the heart was still beating. All the animals were carried to this end-point and were then cut out of the closed system by means of a three-way valve and were resuscitated with oxygen. Only occasionally was it found necessary to resort to artificial respiration. Samples, taken from the closed system at the end of the test, were collected over mercury either in Bailey bottles or Hempel pipettes and analyzed in the manometric Van Slyke apparatus. The samples taken before pneumonectomy showed a clear-cut end-point between 5 and 5.6 per cent oxygen. Following pneumonectomy at the end of the two-month interval, the end-point had risen to practically twice its previous level (11.3 per cent). At the third month the level of oxygen tension in the system was slightly increased to 12.88 per cent (possibly due to an epidemic of acute respiratory infection which swept through the animal house). By the fourth month the level had decreased to about 9 per cent. (For details, see Chart 4.)

III. *Statics and Dynamics of the Respiratory System.*—That there is a compensatory enlargement of the lung remaining after a one-sided pneumonectomy has long been an established fact. There is still, however, little knowledge as to the exact nature of this enlargement. The question of compensatory emphysema vs. a true compensatory hypertrophy is still an unsettled one. Laennec[14] (1819) was the first to speak of pulmonary hypertrophy. In 1929, Celice[15] again raised the question of hypertrophy of the lung. Hilber[16] (1934) claimed that in rats, following the removal of one lobe, the remaining lung areas compensate for the loss not only by a compensatory emphysema but by a genuine regeneration with the new formation of perfectly efficient lung tissue with corresponding new bronchi, new vessels and new respiratory alveoli.

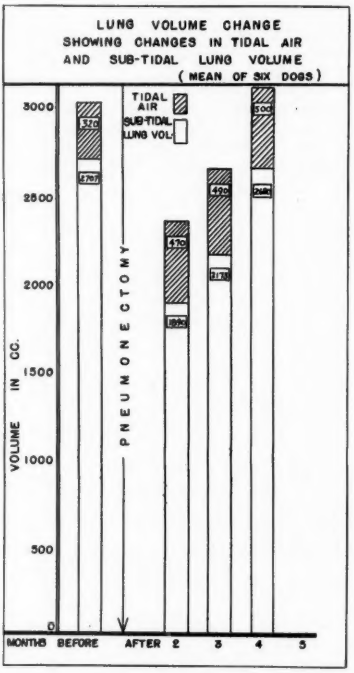

Chart 5.

In order to correlate the change in lung volume with the changes in cardiorespiratory reserve, subtidal lung volume determinations were made at intervals corresponding to the functional tests. The determinations were made according to the method described by Christie.[17] The remaining lung was noted to enlarge so that by the two months following pneumonectomy, the subtidal lung volume has reached 70 to 80 per cent of the preoperative level. Succeeding observations revealed a gradual return toward the normal level (see Chart 5).

The dynamics of the respiratory apparatus at the resting level can best be studied by means of spirometry. Considerable information can thus be obtained. Permanent tracings were kept of the animals' respirations under resting conditions, both before and at intervals after pneumonectomy. An analysis of the records revealed an increase in both the rate and the depth of breathing under resting conditions

following pneumonectomy, with a very considerable increase (35 to 50 per cent) in the tidal air (in Chart 5). This is in accordance with the findings that at high altitudes the volume of the air breathed is increased and remains so after acclimatization has occurred. The increased volume of air breathed greatly diminishes the arterial anoxemia by diminishing the difference between the atmosphere and alveolar oxygen tension.

HEMOGLOBIN CONTENT

Paul Bert[12] (1878) suggested and later verified that the oxygen capacity of the blood was increased at high altitude. Viault[18] (1891) showed that the number of red blood cells and the hemoglobin content are increased at high altitudes. Generally speaking, the percentage of hemoglobin varies inversely with the barometric pressure and even quite small diminutions in the barometric pressure are effective in causing a rise in hemoglobin. Bornstein[19] (1911) and Campbell[20] (1917) found that animals exposed to a higher oxygen tension showed a marked diminution in their red blood cells and hemoglobin. It appears, therefore, that the hemoglobin is regulated in relation to the oxygen pressure of the arterial blood and rises or falls accordingly as this pressure is diminished or increased. The stimulus of the bone marrow by the state of anoxemia leads to a gradual increase in the total amount of hemoglobin in the body. This elevation was for the most part maintained or moderately increased except for two of the animals, in which the hemoglobin returned to the preoperative level.

DISCUSSION AND SUMMARY

Review of the literature not only of experimental pneumonectomy, but of the physiologic changes following pneumonectomy, reveals the fact that most of the observations have been limited to changes under resting conditions. Since it is only under conditions of actually increased tissue demands that the efficiency of the cardiorespiratory unit can be tested, it was decided to attempt to evaluate in accurate physiologic terms the degree of cardiorespiratory impairment following total pneumonectomy and to assay the degree to which the animals could in time achieve a functional adaptation to the anatomic removal of approximately 50 per cent of their pulmonary tissue.

In order to do this a group of healthy young dogs was selected and trained. The physiologic response to varied amounts of moderate strain (one, one and a half, and two hours in the treadmill) and to the most severe strain (anoxemia test), was determined. In addition, studies were made of the statics (subtidal lung volume) and dynamics (rate and depth and character and slope of the curve of respirations) of the respiratory apparatus. The hemoglobin was determined from the total oxygen capacity of arterial blood. In addition some studies were made of the oxygen debt.

The animals were then pneumonectomized, the left lung being removed by separate ligature of the vessel and closure of the bronchial stump being made with silk. An interval of two months was then allowed in order to assure the recovery of the animals to the point that they could bear up under the rigors of the tests. The above observa-

tions were then repeated at monthly intervals and the response to strain was correlated with changes in tidal air, subtidal lung volume, hemoglobin, arterial oxygen saturation, etc.

The results of the exercise experiments may be summarized as follows: The one-hour group showed a slight rise in temperature, pulse and respiration but did not show any unsaturation of the arterial blood after the run of 2,300 meters. Following pneumonectomy the temperature elevation was doubled and the pulse acceleration was tripled. The respirations were slightly increased, and there was but slight unsaturation of the arterial blood. There was a tendency for the temperature and pulse rises to return toward the preoperative levels.

The one and a half hour group following the run of 3,450 meters showed a moderate increase in the temperature, pulse and respiration, but they did not show any decrease in the saturation of the arterial blood. Following pneumonectomy they showed a more marked elevation of temperature, pulse and respiration, and there was a marked decrease in the saturation of the arterial blood. On succeeding runs the degree of unsaturation markedly decreased. Clinically these animals showed much more embarrassment postpneumonectomy than did the one-hour group.

The two-hour group after a run of 4,600 meters showed a moderate increase in temperature, pulse and respirations along with a slight decrease of the saturation of the arterial blood. Following pneumonectomy, the animals showed a very alarming elevation of the pulse and respiration associated with a very marked unsaturation of the arterial blood. On succeeding runs they showed a less alarming increase in pulse and respiration and considerably less unsaturation of the blood, although these values never approximated the preoperative levels. These experiments indicate that as the amount of strain is increased, the pneumonectomized animals show an increasing amount of embarrassment. In short, the cardiorespiratory reserve following pneumonectomy is still sufficient for resting conditions and for moderate exercise. But, as the amount of strain is increased, the impairment of cardiorespiratory reserve becomes increasingly more apparent. On succeeding runs months later there is a tendency for the animals to show increasingly less embarrassment, due to compensatory changes: (1) The increase in the tidal air tends to diminish the difference of the oxygen tension between that of the atmospheric air and alveolar air. (2) The increased subtidal lung volume may increase the functional diffusing area of the lungs. (3) The steady increase in hemoglobin bespeaks more effective carriage of the oxygen to the tissues with a tendency for the blood returning to the lungs to be less unsaturated.

In terms of ultimate strain on the cardiorespiratory unit by means of the anoxemia test, the critical level of oxygen for the normal animals before pneumonectomy showed a clear-cut end-point between 5 and 6 per cent oxygen (average 5.6 per cent oxygen). Following pneumonectomy, this value was found to have risen to practically double its previous value (11.3 per cent oxygen). Four months after pneumonectomy, this level showed a tendency to drop slightly for all animals to approximately 9 per cent. These findings suggest that with pneumonectomy the respiratory reserve is cut in half as a result of the removal of practically 50 per cent of the functional diffusing lung surface area. Within four months after operation, however, some readjustment is occurring whereby the animal can get by on a slightly lower oxygen tension. The nature of this compensatory mechanism is unknown at present. Whether it is on the basis of hypertrophy with or without oxygen secretion (Haldane) or true pulmonary hyperplasia (Hilber) remains yet to be determined. To this end, studies are being made of changes in the relation of the oxygen tension of alveolar air to the oxygen tension of the arterial blood both before and after pneumonectomy. In addition, wax models are to be made of the microscopic structure of the remaining lung at various intervals following pneumonectomy and compared with similar wax models made of the normal lung (removed at the time of pneumonectomy).

We are indebted to Dr. Glenn Cullen for his interest and helpful suggestions, and to Dr. C. C. Wang, who has carried on the analytic portion of the problem.

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INTRATHORACIC ANATOMICAL READJUSTMENTS FOLLOWING COMPLETE ABLATION OF ONE LUNG*

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OVER one year ago a study of the readjustments in the thoracic cage and its contents following total and partial pneumonectomy was made and a series of 45 patients reported upon. Since that time further observations on this original series have been recorded and additional material has been studied. In a large measure the results of the most recent observations tend to confirm the original ones, but to some extent they are contradictory. In view of this fact it would seem advisable to record these data so that they may be available for comparison with other series. It is felt that only in this way may real progress be made. If a careful record is kept of the poor results as well as the good, many of the imponderables, pitfalls and unknowns which now harass those especially interested in the surgery of the lung, may be overcome.

This study is based upon an analysis of 16 cases, in 12 of which a complete pneumonectomy was performed; in 2 a posttraumatic atrophy of the left lung had occurred; and finally in the remaining 2 there was a congenital absence of one lung. Of the group in which complete pneumonectomy has been performed, in 5 the operation was done upon the right side and in 7 upon the left. In 2 cases the lung was removed for tuberculosis; in 8 for carcinoma; and in 2, the first two cases reported, for benign tumors. In this group two patients succumbed to diffuse lobular pneumonia in five days after the operation: one from an unexplained hyperpyrexia associated with negative autopsy findings; and one from a rather acute dilatation of the heart with a resulting heart failure on the fifth postoperative day. Six later deaths occurred, one after six months, from cerebral metastases; two others after three and eight months from tuberculosis of the remaining lung; a fourth, six weeks after operation from pulmonary embolism; one, a year later from generalized metastases; and finally, the first case reported, of a little girl three and a half years old, who was drowned while swimming last summer, three and a half years after operation. Except the patients who succumbed to tuberculosis, autopsies have been obtained in all but one case, thereby providing an opportunity to study the interesting intrathoracic anatomical readjustments which could thus be compared with certain clinical findings as well as with a series of x-ray films taken at regular intervals until just before death. The

*Read before the Nineteenth Annual Meeting of the American Association for Thoracic Surgery, Rochester, Minnesota, May 4-6, 1936.

remaining two patients who are alive reside in Baltimore, and it has been possible to study their clinical course at frequent intervals. The two patients who were examples of what may be called posttraumatic atrophy of the left lung resulting from an injury in early childhood had been examined at the Johns Hopkins Hospital, thirty and twenty years after a crushing injury to the left side of the chest. The two remaining patients were found to have a congenital absence of one lung. As space does not permit the discussion of each individual case in detail, the compensatory changes in general of the entire group will be described, eventual individual variations being noted. A complete clinical report will appear in a later publication, in which each case will be individually and fully discussed.

The restitutional compensatory mechanism following total or partial removal of a lung is based essentially on three factors: (1) on the

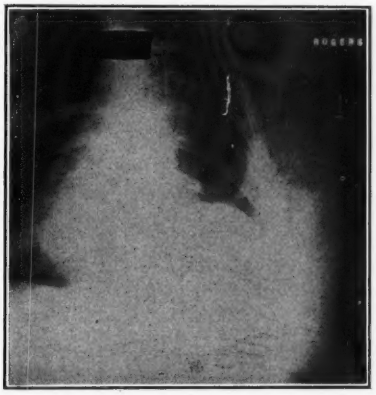
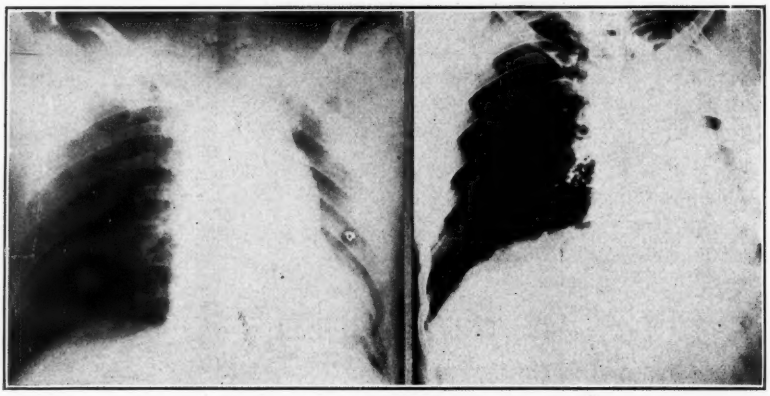


Fig. 1.—X-ray picture of patient on whom total right pneumonectomy was performed, taken thirty minutes after lung was removed and shows pronounced shifting of mediastinum to the right side due to an immediate compensatory dilatation of the left lung. The right diaphragm is very much more elevated than normal, and the space between the ribs on the right side is less than that on the left. The pneumonectomy was complete in the strict sense of the word as the bronchus and vessels were tied before entering the lung parenchyma. The remaining space in the right thoracic cavity was obliterated by an organizing plasma clot. Patient died on fifth postoperative day from diffuse lobular pneumonia of the left lung, and autopsy revealed unobliterated space in right thoracic cavity filled with an organizing plasma clot.

readjustment and adaptation of the thoracic cage and diaphragm on the operated as well as on the unoperated side; (2) on the compensatory dilatation of the remaining lung; and (3) on the production of a space-occupying fenestrated labyrinth of connective tissue which tends to fill the remaining dead space, if any remain when factors (1) and (2), after their maximal restorative efforts, have failed to bring about a complete obliteration of the remaining thoracic space. The mechanism of these three factors is described in their successive order.

1. The readjustment and adaptation of the thoracic cage and diaphragm on the operated as well as on the unoperated side. Immediately after operation for the total removal of the lung, there is a marked difference in the expansion of the thoracic cage on either side. This can be observed even while the patient is still on the operating table. There is practically no movement on the operated side except one that is transmitted; the ribs are obviously immobile and, as shown fluoroscopically and by x-ray films, the diaphragm is much more elevated than normally. There is an immediate, marked shifting of the mediastinum toward the operated side, as shown in Figs 1 and 2, which are x-ray pictures taken thirty minutes and two hours after operation, respectively. It is extraordinary how much shifting of the mediastinum can occur in a relatively short time. The size of the thoracic cage on the operated side shows a marked reduction, because



A. *B.*

Fig. 2.—*A*, X-ray picture taken two hours after total left pneumonectomy emphasizes as in Fig. 1 the immediate compensatory dilatation which takes place when one lung is thrown out of function by removal. It will be noted that there is a marked expansion of the remaining right lung which has caused the dome of the right thoracic cavity to be elevated higher than that of the left. The interspaces are wider than on the left side and the mediastinum is pushed over, almost completely obliterating the left. This compensatory mechanism occurred within two hours following removal of the left lung.

B, One year and a half after operation the same patient as shown in Fig. 2*A*, but with lipiodol injection, demonstrating that the compensatory dilatation of the left lung immediately following operation has increased very little over a period of a year and a half. The left bronchial stump can be seen to be filled with lipiodol high in the left thoracic cavity. There is apparently no unobliterated dead space present. The patient was forty-two years of age at time of operation. The point to be noted is that compensatory dilatation in this case was almost complete within two hours immediately following operation.

of this shifting of the mediastinum as well as the elevation of the diaphragm. The interspaces between the ribs are smaller on this side, and because of the compensatory dilatation of the remaining lung, which began within the first twenty-four hours, are wider on the normal side. This factor causes always, to a certain degree, an immediate scoliosis of the spine toward the operated side, which again serves to

diminish the empty remaining space. The thoracic cavity on the operated side is reduced not only in the lateral diameter but in all of them, particularly the anteroposterior. Furthermore, a disparity in the size and height of the apex or dome of the thoracic cage develops owing to disuse of the one side. After some days the separation of the ribs on the unoperated side becomes more pronounced, while the reverse is true for the opposite side. The thoracic cage of the former is increased in all diameters. The diaphragm, owing to the compensatory dilatation of the remaining lung and the consequent increase in its volume, becomes permanently established at a much lower level than it normally occupies. The costophrenic sinus still exists, but it is much more obtuse or shallow than normal, and instead of being at about the level of the costal margin the apex is very much more

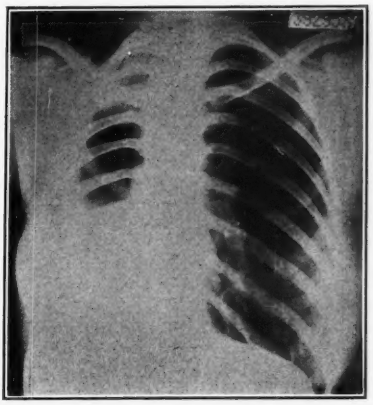


Fig. 3.—X-ray film of patient three and a half years after total left pneumonectomy for carcinoma of the primary bronchus shows marked compensatory dilatation of the remaining right lung.

deepened and extends well down below into the peritoneal cavity. Thus the increase in volume of the lung and size of the chest occurs in all, the transverse, the anteroposterior and the vertical dimensions (Fig. 3). The acting forces are in marked contrast on the two sides. On the one side, there is an elevation and immobilization of the diaphragm, a temporary scoliosis to the same side, a contraction of the intercostal spaces, a lowering of the dome of the thoracic cage, a shrinkage in the anteroposterior and lateral diameters with a shifting of the mediastinum toward the operated side. On the other side, the thorax is enlarged in just the opposite directions; i.e., the dome of the thoracic cage is elevated, the intercostal spaces are wider, all diameters of the thoracic cage are increased, the diaphragm is deflected downward, the costophrenic sinuses are markedly enlarged in size, and the mediastinum is shifted away toward the opposite side. The readjust-

ment of the thoracic parietes, i.e., of diaphragm and thoracic cage, following partial pneumonectomy differs only in degree from the above described changes which accompany complete ablation of a lung.

2. The compensatory dilatation of the remaining lung begins immediately after operation, whether the latter is a partial or a complete pneumonectomy. The difference in this factor of the compensatory restitutional mechanism is one of degree only, being of course greater after an entire removal than after a partial resection of the lung. The increase in volume of the remaining lung, after a complete pneumonectomy, manifests itself by an immediate exaggeration of the respiratory excursion of the unoperated side of the thorax. Further, the objective evidence determined by x-ray films has just been described under the first factor of the compensatory mechanism. The constant increase in the measured vital capacity also bears witness to this compensatory dilatation. A final proof is found in the added anatomic and histologic changes observed at autopsy.

There has been some difference in the degree of the compensatory dilatation in the 8 subjects of total pneumonectomy that survived operation, but in all of them some hyperdistention of the remaining lung occurred. This difference in degree seemed not to depend on the age of the patient and appeared to be more pronounced after total left than after right pneumonectomies. Why this should be so is not clear from an anatomic point of view unless it has to do with the rotation and displacement of the heart.

In the five cases of total left pneumonectomy for tumors of the lung, in the two patients with traumatic atrophy of the left lung, and in the patient with congenital absence of the left lung there has been an enormous compensatory dilatation of the remaining right lung. In the first case operated on and reported and in the traumatic cases the patients were small children, aged three, three and a half, and nine years, respectively, at the time of their operation and accidents. In these and in the congenital case the restitutional compensatory dilatation was complete, and the right lung almost entirely filled the left thoracic cavity by displacing the mediastinal contents to the left posterior portion of the thorax. In one of the other patients, however, on whom a total left pneumonectomy was performed, an elderly woman sixty-eight years of age, it was possible to observe the development of the compensatory mechanism from the clinical standpoint and later to compare those findings with direct observations made at autopsy, for death from metastases occurred six months after operation. Because of the age of this woman and the completeness of the restorative compensatory dilatation of the remaining right lung, together with anatomic proof of the clinical findings, this case may be described in detail as an example showing that old age is no barrier to complete

anatomic and physiologic readjustment. The remaining 6 cases of total removal of the left lung have, with minor exceptions, presented the same clinical and x-ray evidence of compensatory readjustment; and it is therefore likely that their anatomic changes are not dissimilar.

Further corroborating evidence of the compensatory readjustment following ablation of the entire left lung was observed at the operation upon two patients with traumatic atrophy and, at autopsy, on one with congenital absence of a left lung. The clinical observations and opera-

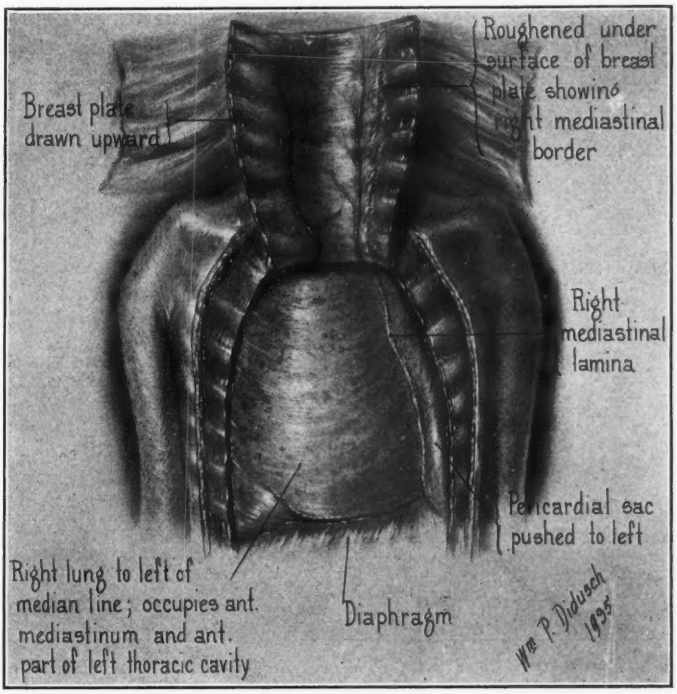

Roughened under surface of breast plate showing right mediastinal border
Breast plate drawn upward
Right mediastinal lamina
Pericardial sac pushed to left
Right lung to left of median line; occupies ant. mediastinum and ant. part of left thoracic cavity
Diaphragm
Wm P. Didusch 1935

Fig. 4.—Drawing made at the time of autopsy of patient sixty-eight years of age, who died six months after entire left lung was removed. The readjusting compensatory mechanism in this case was complete.

tive and autopsy findings corroborate in every respect the compensatory changes observed in the above mentioned operative cases. It would seem that the clinical and autopsy findings in the case of total left pneumonectomy in the patient sixty-eight years of age, as well as the autopsy findings in the cases of congenital absence of the left lung, supplemented by the clinical observations on six cases in which a total left pneumonectomy was performed, as well as the clinical and operative findings in the two cases of traumatic atrophy of the left lung, furnish sufficient data to formulate a fairly accurate picture of the

intrathoracic readjustment following total left pneumonectomy. In such cases the remaining right lung undergoes in all three lobes a pronounced dilatation, so that the thoracic cage becomes enlarged in all diameters as above described. The upper lobe distends and protrudes into the lower cervical region through the superior opening of the thorax bounded by the first rib. The upper ribs seem to be elevated and show less of a downward slope. The medial surface of the upper lobe bulges toward the midline, displacing the lower end of the trachea to the left side. In all these cases this tracheal displacement extended to the left parasternal line. Also the posteromedial surface of the upper lobe, as shown at autopsy, burrowed behind the trachea

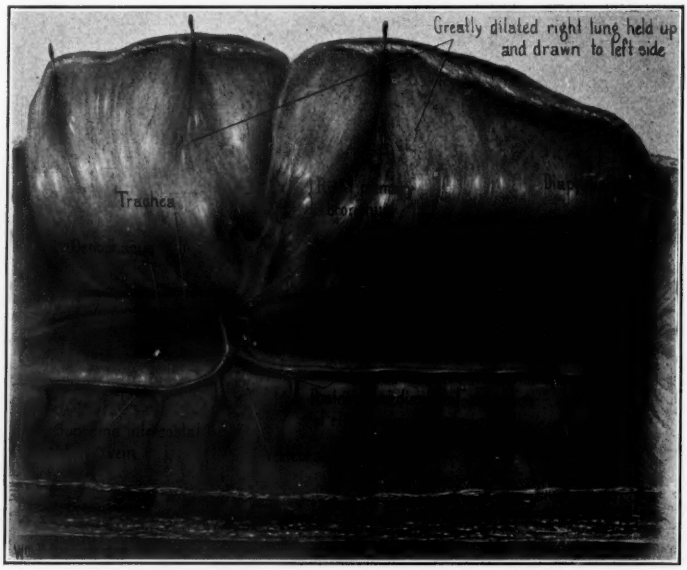


Fig. 5.—Drawing made at the time of autopsy of patient sixty-eight years of age, who died six months after entire left lung was removed. The readjusting compensatory mechanism in this case was complete.

pushing the parietal pleura in front of it and crossing the midline into the left pleural cavity through the posterior mediastinum in front of the bodies of the vertebrae but behind the esophagus and trachea. (Fig. 5.) Below, this pseudopodial-like extension of the lung was interrupted by the azygous vein and bifurcation of the trachea. The anteromedial portion of the upper right lobe extended across the midline in the anterior mediastinum, entering and filling the upper anterior portion of the left thoracic cavity. The innominate artery and the veins define the upper border of this protruding portion of the right upper lobe. The middle and lower right lobes also expand through both the posterior and anterior mediastinum. (Fig. 4.) The postero-

medial portion of these lobes extended across the midline in the posterior mediastinum from the level of the bifurcation of the trachea to the diaphragm. (Fig. 5.) This lappet or tonguelike process of lung crossed the midline in front of the bodies of the thoracic vertebrae and the aorta, and was behind the esophagus. The extensions of the lung into the left posterior thoracic cavity measured about 6 cm. to the left of the midline. The entire mediastinum and its structures were shifted to the left of the midline, and the space thus vacated was occupied by the bulging right lung. The heart was rotated into the

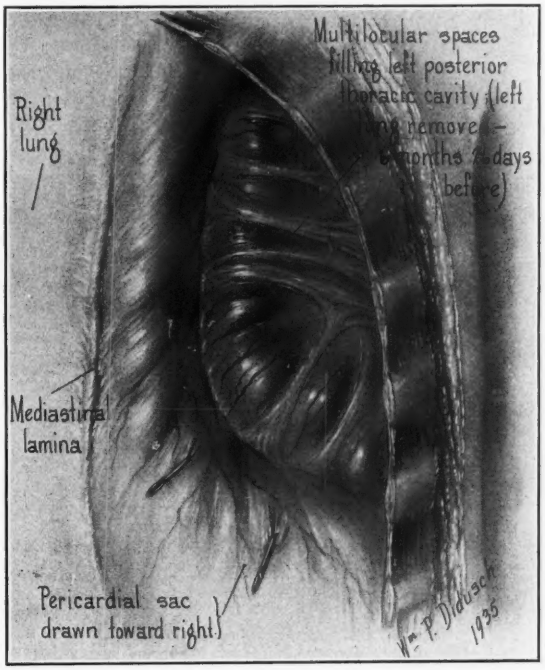


Fig. 6.—Drawing made at the time of autopsy of patient sixty-eight years of age, who died six months after entire left lung was removed. The readjusting compensatory mechanism in this case was complete. It is to be noted that the obliterating multilocular cystic area has filled the remaining empty space after the compensatory dilatation of the right lung was complete.

lateral portion of the left vertebral gutter to make room for the large lappet of lung arising from the anteromedial surfaces of the right middle and upper lobes, bulging through the anterior mediastinum to fill completely the anterolateral portion of the left thorax. The posteromedial portion above the heart, in an area that was incompletely filled with lung tissue in the sixty-eight-year-old patient, had become occupied by a multilocular space-filling mass of fibrous tissue which was composed of many small cystlike spaces filled with sterile clear

fluid (Fig. 6). While the patient was alive and well, these small spaces could be defined in the x-ray film. Thoracotomy for the release of extrapericardial adhesions, performed on two patients with posttraumatic atrophy of the left lung, corroborated in the living patient all that was observed in the above described case at autopsy. When the left thoracic cavity was opened, a large empty space was perceived in which the left lung was represented by a small fibrotic mass about 10 × 5 × 3 cm. in dimensions (Fig. 7). The left pulmonary artery had become obliterated, and there had also occurred a complete obliteration of the left primary bronchus. The heart at that time was in an approximately normal position but could be moved posteriorly with ease. By means of positive intratracheal pressure (20 mm. Hg) the right lung could be filled to its capacity, and the crossing over from the right to the left thoracic cavity could in this way be directly

Fig. 7.—Lipiodol injection demonstrating blockage of the left primary bronchus and the presence of the right lung in the left thoracic space. The compensatory dilatation of the right lung and the right thoracic cavity is also observed. These identical x-ray findings were present in two cases of posttraumatic atrophy of the left lung.

observed in both the posterior and the anterior mediastinum (Fig. 8). The lung actually passed across the midline in front of the thoracic vertebrae, below the bifurcation of the trachea, and in front of the aorta, bulging through the posterior mediastinum into the left thoracic cavity, and filling the vertebral gutter of that side. The thoracic aorta was not as fixed as usual but had a loose attachment that might aptly be described as a mesentery with a definite elongation of the intercostal arteries. This mobility of the aorta was probably brought about by the shifting of the heart and therefore also of the aortic arch. In the anterior mediastinum, before the positive pressure was used, a very large defect could be seen into which both hands easily could be inserted for some distance to the right of the midline. With a positive pressure of 20 mm. Hg a huge lappet of lung protruded across

the midline displacing the heart in the lateral and posterior directions with some rotation of the transverse arch (Fig. 9). This bulging right lung, mainly the upper and middle lobes, would fill the entire left

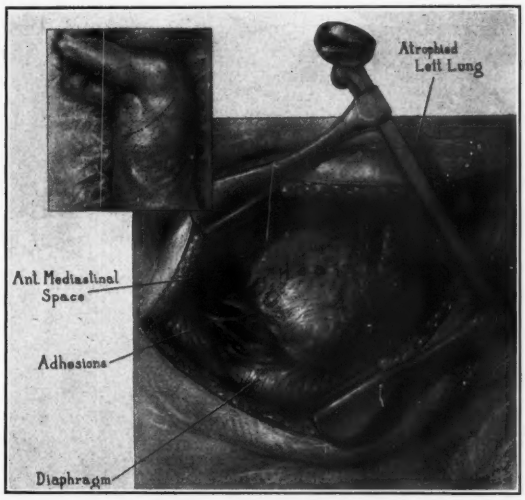


Fig. 8.—Operation on first case of posttraumatic atrophy of left lung for release of extrapericardial adhesions. The insert shows location of incision and self-retaining retractor employed.

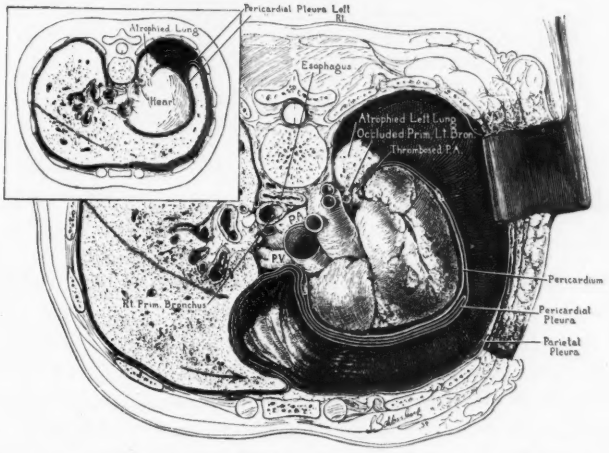


Fig. 9.—Diagrammatic sketch made at operating table of intrathoracic findings in first case of posttraumatic atrophy of the left lung. The insert shows the right lung expanded under positive pressure.

chest with the exception of the space occupied by the mediastinal structures and heart (Figs. 10 and 11). The coincidence of two such unusual cases calling in the Out-Patient Department within one month

of each other was rare indeed! Both patients complained of precordial pain on exertion, and both were diagnosed as having posttraumatic atrophy of the left lung with extrapericardial adhesions. Their clinical manifestations were worked out by Dr. John T. King, Jr., and Dr. John Eager Howard. Even the accidents which befell these unfortunate but extraordinarily lucky patients were quite similar. The younger had been run over at the tender age of three by a huge farm harvest wagon loaded with oats. The ground was muddy and soft and after the front and back wheels of the wagon passed over the child's chest, more dead than alive, with blood running from his nose and mouth, he had to be dug out of the dirt. He remained in bed for one year following the accident. Since then up to the present he had been

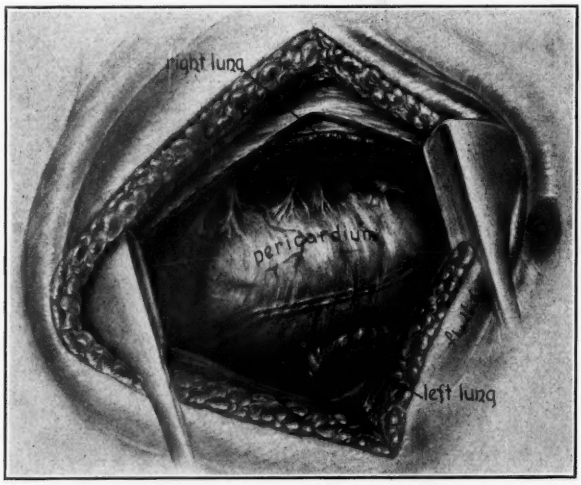


Fig. 10.—Operative exposure of second case of posttraumatic atrophy of left lung. Extrapericardial adhesions can be seen at the upper portion of the figure, underlying the temporarily collapsed anterior mediastinal prolongation of the right lung.

normal in every respect, doing very heavy work as a truck driver. The second patient had been run over by an automobile touring car at the age of nine years, and suffered from identical injuries that the first patient received. The only difference was that in the older child there were a few residual bony changes leaving the thoracic cage slightly asymmetrical; whereas no evidence of injury could be found in the ribs of the first child. It would seem likely that in both these cases the cartilaginous thoracic cage had been pressed in by the crushing weight thrust upon it and came back into its normal position from the spring of the ribs following removal of this force, very much like the opening of an opera hat. This terrific pressure in the meanwhile, however, had crushed the left primary bronchus and the left pulmonary artery

against the bodies of the vertebral column. The obliteration of the artery by thrombosis and the bronchus by cicatricial stenosis resulted from this crushing against the spinal column. After release of the extrapericardial adhesions both patients were completely relieved and returned to their work. They are in excellent health at the present time and are occupied in strenuous, laborious occupations.

In the entire records, both clinical and pathologic, of the Johns Hopkins Hospital, not counting the Out-Patient Department, there have been but two instances of congenital absence of one lung. This series consists of over 150,000 patients and an additional 14,000 autopsies. These latter figures are mentioned just to give an idea of the extreme rarity of this condition. In one instance the patient died

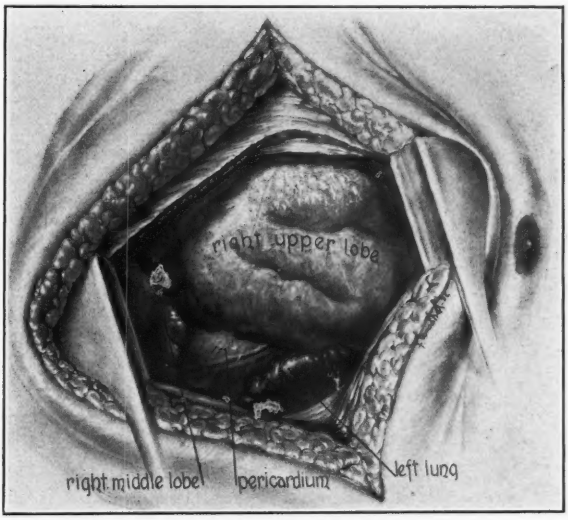


Fig. 11.—The right lung partially expanded, showing the fact that the right upper lobe tends to fill the upper left portion of the thoracic cavity with the right middle lobe filling the lower portion of the left thoracic cavity.

on the Urological Service of a pneumonia following a septicemia secondary to a dilatation of a urethral stricture. The patient was fifty years of age at the time of admission to the Urological Service, and was suffering from tabes dorsalis and pyelonephritis. A routine physical examination had revealed some dullness on percussion and absence of vocal fremitus as well as breath sounds, over the posterolateral surface of the left chest. However, even though the point of maximum impulse of the heart was in the fifth interspace in the midaxillary line, the absence of one lung was not suspected until an autopsy was performed December 5, 1919, autopsy No. 5818, revealing the total absence of the left lung. This patient up until the time of his death was a very active man, even in spite of the fact that he had tabes.

He never complained of shortness of breath or any other incapacitation as far as the cardiorespiratory mechanism was concerned. The drawings made at the time of autopsy (Fig. 12) reveal a most interesting intrathoracic readjustment due to the compensatory dilatation of the right lung. The right upper and middle lobes have expanded to many times their normal size and filled the left upper thoracic cavity. Even the right lower lobe has come across the midline to some extent. The heart has been pushed to the left side. The posterior view (Fig. 13) is even more interesting in that it shows the trachea in the midline in its upper portion but rotated to the right and on its long axis in the lower portion, with a small nubbin of undeveloped left bronchus. There is practically no difference in the diameters of

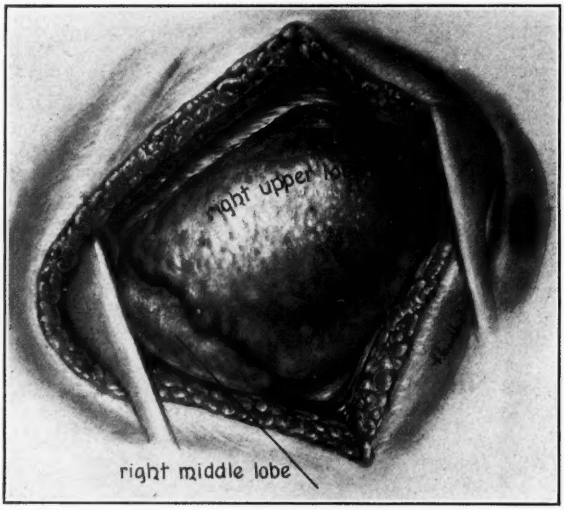


Fig. 12.—The right lung entirely expanded by increasing the intrapulmonary pressure, showing the right lung not only completely filling the left thoracic cavity but bulging out of the incision.

the trachea and the right primary bronchus. The prolongations of the right upper and middle lobes, as shown in the drawings, have completely filled the left upper and anterolateral portion of the left thoracic cavity. Even more interesting, however, is the medial pseudopodial prolongation of the lower lobe in the thoracic cavity which is posterior to the esophagus but in front of the aorta, and filling the left thoracic space behind the heart and pericardium. It may be seen that the esophagus is displaced to the left side. The heart and great vessels are also most interesting, as shown in Fig. 14. The heart is rather a square shape with a total absence of the left pulmonary artery. The pulmonary aorta is continuous with the right pulmonary artery, the latter being very much larger than normal. There is not even any

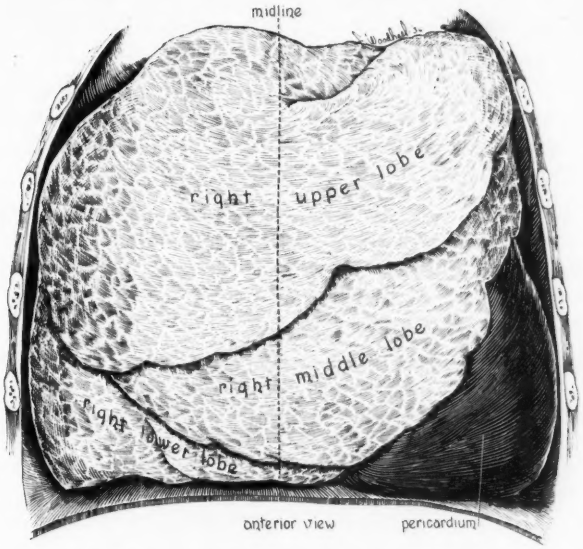


Fig. 13.—Drawing made at autopsy of patient fifty years of age, with congenital absence of the left lung (anterior view).

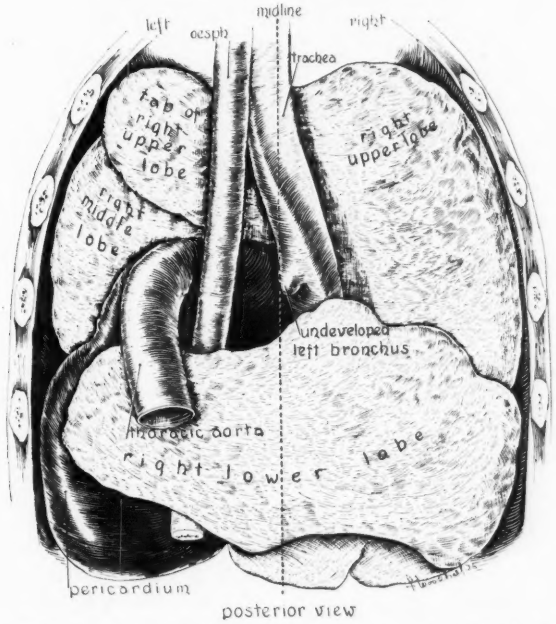


Fig. 14.—Posterior view of patient shown in Fig. 13, demonstrating the anterior and posterior lingulae of the right lung moving over to fill the left thoracic cavity, in addition to the displacement of the heart and great vessels. The nubbin of undeveloped left bronchus may be seen, as well as the very interesting rotation of the left bronchus in its own axis.

outpouching where the left pulmonary artery might have come off. The left innominate vein runs directly into the right auricle; whereas the right innominate vein is the only tributary other than the azygos vein to form a very small superior vena cava. It was also shown that the right pulmonary veins were very much larger than normal, emptying into the left auricle, and also that there was a total absence of the left pulmonary veins. On microscopic sections, the structure of the very much enlarged right lung was entirely normal. There was not the slightest suggestion of fragillation of elastic tissue or emphysema; so this patient had therefore lived fifty years with one lung without any deformity of his chest wall or any apparent cardiorespiratory embarrassment. How long he would have lived had he not been a victim

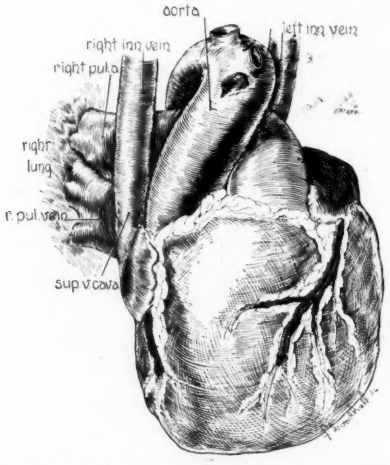


Fig. 15.—Drawing of heart from case of same patient with congenital absence of left lung, showing left innominate vein running into right auricle and right innominate vein and small superior vena cava. Also, total absence of left pulmonary veins and the enormous enlargement of the right pulmonary veins. Peculiar square shape of the heart also evident.

of venereal infection it is, of course, impossible to say, but certainly his length of life should not have been shortened in any way due to the absence of one lung.

The second case was that of a complete absence of the right lung. This occurred in a patient admitted to the Harriet Lane Home for children, a negro child who was the victim of many other congenital anomalies, one of which was an imperforate anus. The child was therefore operated upon when a colostomy was made. The patient survived four and a half months, when suddenly, while still in the hospital, he became cyanotic and died immediately. At autopsy the clinical impression of a total absence of the right lung was confirmed (Fig. 15). The heart was abnormally large, and there was a patent

foramen ovale, and also a patent interventricular septum. Whether or not these latter had anything to do with the sudden death could not be determined. As was found in the postoperative cases, the compensatory dilatation in this case of congenital absence of the right lung was not so pronounced in the remaining left lung as was the compensatory dilatation of the right lung in the instance of absence of the left lung. Nor was the heart displaced as much to the right side as to the left. At autopsy there was a very definite space between the right side of the pericardial sac and the chest wall. This probably existed in the living subject, as it could be seen in the x-ray of the chest (Fig. 16). A drawing made at the time of the autopsy revealed the interesting fact that the dilated upper left lobe was mainly respon-

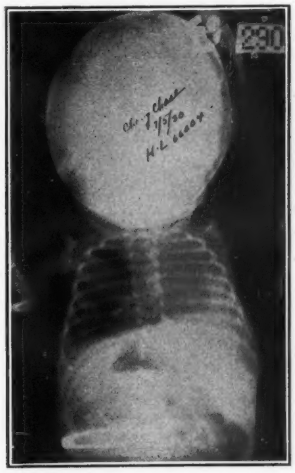


Fig. 16.—X-ray of baby four and a half months of age, showing congenital absence of right lung with heart displaced to right side.

sible for the filling of the anterior mediastinum as well as the displacement of the heart and great vessels to the right (Fig. 17). The left auricle was of normal size but the right was enlarged. This was undoubtedly due in part to the patent foramen ovale. The trachea merged into the left primary bronchus imperceptibly (Fig. 18). There was a small nubbin which indicated the location of the primordium of the right pulmonary artery (Figs. 19 and 20). This anlage was not present in the above cited instance of congenital absence of the left lung.

Following destruction of the *left* lung, whether by operation, trauma, or congenital absence, these above cited cases probably represent the ideal complete restitutional compensatory readjustment and demonstrate conclusively that these readjustments may take place without

incapacitating the individual physiologically. The ages of patients in which the left lung was removed in the 7 operative cases were 3½, 21, 26, 30, 42, 45 and 69 years; while those of the traumatic cases at the time of injury were 3 and 9 years. In all of them the compensatory readjustment has been similar with only minor exceptions, nor has it been necessary in any of them to perform a thoracoplasty. The subjects of the traumatic cases have lived for thirty and twenty years, respectively, without the least circulatory or respiratory disturbance from distortion of the mediastinal vessels or structures. The patients operated upon and still alive also have been

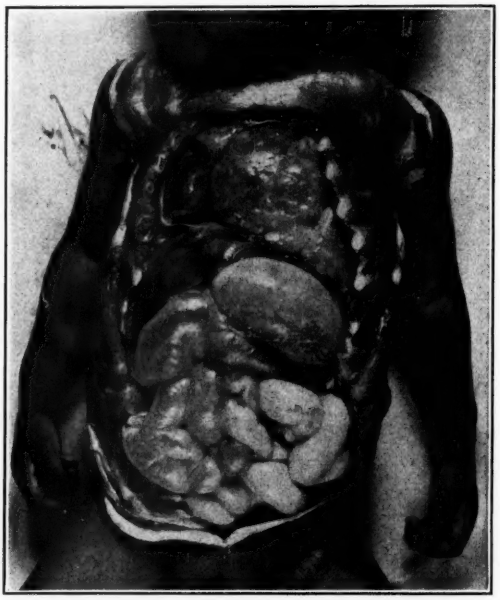


Fig. 17.—Photograph made at autopsy of child with congenital absence of right lung. Compensatory enlargement of left lung is shown, with displacement of the heart to the right side.

able to resume their normal active lives and have remained without any morbid symptoms, the period of time elapsed since their operations ranging from three and a half years to six months. The first patient upon whom a total pneumonectomy was performed in the Johns Hopkins Hospital in June, 1933, reported in the *Journal of the American Medical Association*, was a little girl three and one-half years of age. The tumor while occupying the entire left bronchial tree had also impinged on the opening of the right primary bronchus so that a total left pneumonectomy was imperative to save the child's life. She had a completely uneventful convalescence, and in a short time, about one month, the remaining right lung had expanded entirely to fill the left

thoracic cavity except that portion which was occupied by the heart. This patient grew normally and was a perfectly healthy, vigorous child. She returned to the hospital many times for complete follow-up studies, which each time revealed a perfectly normally function-

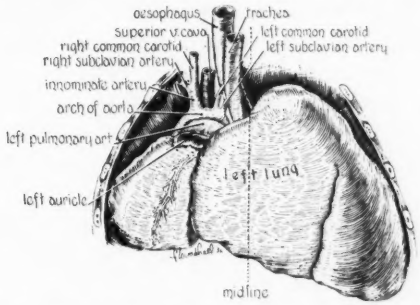


Fig. 18.—Drawing made at autopsy of four-and-a-half-year-old child. Congenital absence of right lung. Note square shape of heart, pushed over to right side. It does not completely fill the right thoracic cavity. Space in the upper posterior and anterior portion of the right thoracic cavity unfilled. Greatest amount of compensatory dilatation has occurred in upper lobe of left lung.

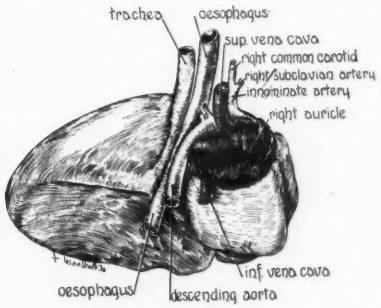


Fig. 19.—Posterior view of Fig. 18, showing enormous dilatation of right auricle, rotation of trachea to left side, right primary bronchus entirely absent.

Fig. 20.—Sketch of pulmonary aorta and pulmonary valves showing nubbin of right pulmonary artery which represents the anlage that never developed.

ing cardiorespiratory mechanism! Last July, while on a picnic at the age of six and one-half years, she was drowned swimming in a river. The parents had their local physicians perform an autopsy and very considerately sent the heart, great vessels and lungs to me for

further study. A letter from the physician stated that when the chest was opened the right lung appeared very much enlarged, occupying not only the entire right thoracic cavity, but also the anterior mediastinum and left thoracic cavity as well. The heart was in contact with the left chest wall and rotated posteriorly, of course, occupying some portion of the left thorax. The stump of the left bronchus which had been closed with interrupted silk sutures was perfectly healed. The end of the stump was composed of a mass of scar tissue toward which the lumen tapered. Bronchial epithelium covered the entire lumen, having grown over the blind sutured end. The silk sutures were some distance from the lumen. The entire remaining bronchial stump was smaller than normal, probably a result of atrophy from disuse. Sections from the lung revealed the same type of compensatory dilatation encountered in the dog experimentally. The definitive respiratory unit, consisting of alveoli, air sacs, atria and ductus alveolaris, were dilated about a third again the size of a normal six-and-a-half-year-old child's lung. The alveolar walls were everywhere intact and of normal thickness. No fragillation of the elastic tissue was encountered. No evidence of emphysema was found. There was no hypertrophy of the heart, the latter being normal in every respect. The thymus was about three times normal in size. The latter had not given rise to any signs or symptoms during life and could not be seen in the roentgenograms frequently made of the chest. This enlargement of the thymus has therefore been regarded as purely coincidental, and an irrelevant finding. To sum up, after the child had lived over three years with only one lung, there was nothing to indicate that the ensuing compensatory dilatation of the remaining lung was in any way deleterious to the function or anatomic structure of that lung. The restitutional compensatory readjustment in this case had been complete from a physiologic as well as an anatomic point of view. In two of the patients upon whom a total left pneumonectomy had been performed there developed, after two weeks, very small but definite openings in the left primary bronchus which became connected with small, walled off, pleural cavities that have slowly but constantly diminished in size; and, while the period of intrathoracic adjustment for that reason seemed delayed, it was nevertheless finally accomplished without further resort to surgical measures.

It would seem, therefore, that the entire left lung may be removed with the assurance that the empty space ensuing will be filled, and that in the absence of generalized infection of the pleural cavity further thoracoplastic procedures will be unnecessary.

3. The formation of a space-occupying fenestrated labyrinth of connective tissue. In the first two total left pneumonectomies reported, attention was called to the fact that the empty space resulting from

the removal of the left lung was immediately filled with a serosanguineous exudate, composed in the main of plasma and some cellular elements, all of them derived from the blood stream. This seems indeed to be the modus operandi by which the body tends to obliterate dead or empty spaces created within its confines, whether the latter be caused by the surgical removal of a portion or by congenital absence. The fluid contents of many of the well-known cysts throughout the body, especially of the lung, might result therefrom. That in all the operative cases this accumulation of plasma has occurred was proved by diagnostic thoracenteses of small amounts and by repeated x-ray films.

After some hours, coagulation of the main portion of this mass occurs, and from the entirely fluid medium fibrin is precipitated, which forms a fragile scaffolding, so to speak, in which there are many different sized pockets containing serum. The fibrinous skeleton in time becomes organized by fibroblasts growing in from the chest wall, and finally, what at first was a homogeneous mass of fibrin, becomes transformed into a multiloculated space enclosing honeycombed mass of fibrous tissue which contains, in turn, fluid in small labyrinthian-like spaces. This mass, which may be very small or may occupy the entire thoracic cage, acts alone but efficiently as a filler of the space not occupied by the compensatory dilatation of the remaining lung tissue. Such formation of small multilocular spaces occurs also after partial pneumonectomy. Particularly is this true when an upper lobe has been removed; and, when the chest is finally healed, it is almost impossible to distinguish this spongelike tissue mass from lung parenchyma. In resections of the lower lobe, the remaining upper lobe at first drops down but has in our series invariably reexpanded, filling last of all the apex of the thoracic cage. Eventually the one superior, right or left, lobe expands to occupy the entire remaining space. Quite different are the conditions following resections of the upper lobe. In them the resulting empty space is incompletely filled by the remaining lower lobes, so that the apical region of the thorax becomes occupied by this multilocular mass of fibrous tissue instead of by lung parenchyma.

Of the five patients on whom complete right pneumonectomy was performed, all have by this time died: two of pneumonia of the left lung five days following operation; one six weeks later of pulmonary embolism; one, of dilatation of the heart on the fifth day postoperative. This patient suffered from auricular fibrillation before, during and continuously after the operation; one succumbed after one year from generalized metastases. This patient, fifty-four years old, was on the border of inoperability at the time the lung was removed. Daily diagnostic thoracenteses and x-ray examinations before death showed that in all cases there was an accumulation of plasma within twenty-four hours after the operation, filling the entire right thoracic cavity. This

plasma was, in these as in the other seven cases of total pneumonectomy, always sterile. As in the other cases, so it proved to be in these, that the daily aspirations of fluid became less easy and the fluid itself less in amount. The character of the aspirated contents has been always the same, i.e., a serosanguineous fluid which will almost always clot on standing in a glass tube. A smear of this fluid reveals a majority of red blood cells with some polymorphonuclears and small lymphocytes, the white cells being much less in proportion to their normal occurrence in the blood stream. The cellular elements will settle down to the lower portion of the thoracic cavity so that, with the patient in a semisitting posture, aspirations at higher levels reveal a clearer fluid. Air, some of which is always trapped within the chest cavity during and after closure of the wound, rises to the upper part of the cavity where it is slowly absorbed. Owing to the fact that, when the patient is elevated into a half sitting position, the posterior inferior portion of the thorax is filled with the plasma exudate, the entrapped air fills the superior anterior portion. After forty-eight to seventy-two hours this mass of fluid becomes coagulated and resembles in all respects ordinary blood clot. The deeper color is noticed in the bottom of the mass, where also the cellular elements accumulate. However, throughout this mass of clot cystlike areas appear which contain a serum that on smears proves to be free of all cellular elements. This is again an occurrence similar in all respects to the accumulation of serum formed around the blood clot in a test tube; it is the retraction of the clot that causes formation of the small cystlike areas. The film skeleton becomes organized into a fibrous mass with the usual contraction, thus causing an elevation and an immobilization of the diaphragm as well as an immobilization of the chest wall, a retraction of the ribs and a diminution of the interspaces. In two patients who died five and fifty days following a right total pneumonectomy, this organizing mass of coagulated material was observed grossly and also microscopically. In these four cases of right total pneumonectomy, although there was some shifting of the mediastinum, the major rôle in the obliteration of the remaining dead space was played by the formation of such a fibrinous mass which, in the fifty-day case, was beginning to undergo organization. It is likely that the remaining left lung, unlike the right, may not be able to cross the midline and fill the other side of the chest. This, again, may be due to the fact that the anatomic circumstances would prevent this change. For instance, as the left lung consists of only two lobes, the displacement and rotation of the heart to the left are mechanically easier of accomplishment than to the right. This emphasizes further that, although the remaining lung fails to fill the contralateral thoracic space after total pneumonectomy, the readjustment of the thoracic parietes together with the formation of this multilocular fibrous mass may cause

the obliteration of that space. This is similar to the organization of a blood clot in the blood clot operation originally described by Schede. This obliteration if it occurs would, as in three of the cases, render collapse of the thoracic cage by thoracoplasty unnecessary. In the event of an infection the clot would probably be completely or partially destroyed, and under these circumstances an obliteration of the remaining dead space delayed or perhaps prevented, so that some form of thoracoplasty would have to be resorted to.

SUMMARY

Although this series of cases is relatively large, it is actually small, and to draw very definite conclusions from it would be incorrect; nevertheless it is only fair to state that this experience so far teaches that thoracoplasty or the resection of ribs may be given up, certainly as a primary procedure, and that in all probability, particularly in clean cases, it will be unnecessary to perform any type of thoracoplastic operation. It would also seem that it is unnecessary to do a phrenicectomy before or during the operation of total or partial pneumonectomy. For it is the piston action of the diaphragm on that side against the rigid intact wall of the thorax on both sides that brings about the so necessary expansion of the remaining lobes following partial pneumonectomy; and it is, as a rule, either completely immobilized or practically so on the operated side for some time following total pneumonectomy. It would also seem probable that at a later date the activity of the diaphragm on the operated side returns with the filling of the thorax by the dilatation of the contralateral lung. Hence it follows that interference with the normal anatomic or physiologic condition of the thoracic parietes after total or partial pneumonectomy, in our present state of knowledge, may be unnecessary, if not actually harmful.

It is of course advisable not to drain the remaining empty space following total pneumonectomy, because this is immediately filled, as shown, with a coagulated mass of plasma that undergoes later organization with the production of a fibrous tissue mass that occupies a space of greater or less size, depending on the cavity that eventually has to be filled. It is interesting that not only in total but also in partial pneumonectomy, if the remaining lung undergoes a compensatory dilatation, this multiloculated cystic mass of fibrous tissue is compressed by the encroaching lung or lobe and gives way as the space is occupied by the gradual enlargement of the remaining lung tissue, the final result being that the space which normally would be occupied by lung but is not becomes filled by this labyrinthian, cystic, fibrous-tissue body. As stated above, this may, as it is in cases of total right pneumonectomy, be so great as to occupy the entire remaining thoracic cavity or it may fill only a very small portion.

It should be stated that in the experimental studies recorded in the *Bulletin of the Johns Hopkins Hospital* (67: 373, 1935), and also in the sections of the lung in the sixty-eight-year-old woman, the two congenital cases, and the specimen of the first case of three and a half years' duration, there has been found no histologic evidence whatsoever of emphysema of the remaining lung. Emphysema should be distinguished from compensatory dilatation, for in the latter there is no fragillation of the elastic tissue surrounding the definitive respiratory unit consisting of the alveoli, air sacs, atria, and alveolar ducts. Emphysema is a pathologic condition in which there is an interruption of the elastic tissue.

There has been quite marked tracheal displacement in all these cases, but it is to be noted that there has been no displacement or rotation of the heart to the right side similar to rotation noted to the left side. This may be impossible but, if it were, might well give rise to disturbance of the circulation; for, from a mechanical standpoint, rotation of the heart to the left and posteriorly would cause much less disturbance in the angulation or twisting of the aorta than would the same degree of displacement to the right side. The question again arises, is it possible for a patient to survive with as marked a displacement of the heart to the right side as to the left? This displacement to the right would constitute a dextrocardia, which may cause an interference with the filling of the heart with return venous blood. It may be found advisable in instances of operative removal of the right lung, in which the thoracic cavity is not completely filled with an organizing plasma clot, to resort to some other method of obliteration of the right thoracic cavity, i.e., some form of thoracoplastic procedure. Again it may be preferable to remove the right lung in two stages, i.e., to ligate the right pulmonary artery and free the lung from any binding adhesions connecting it to the chest wall in the first stage. Amputation of the lung is performed in the second stage, which allows the patients to adjust themselves to a gradual shifting of the mediastinum as well as a slow obliteration of the right thoracic cavity. This two-stage method also affords an opportunity for the patient to become accustomed to the shunting of the circulation through one lung as a result of the ligation of the right pulmonary artery. The pulmonary veins should be left intact as the blood supplied from the small bronchial artery must be adequately drained away, or else a moist gangrene of the lung will develop. Circulation through the bronchial artery is adequate to keep the pulmonary tissue viable when the pulmonary artery on the same side has been ligated.

We have been able to elicit no evidence whatsoever that compensatory dilatation of the lung, in either man or animal, is harmful. It is only necessary to point to our two cases of traumatic atrophy of the

left lung of twenty and thirty years' duration, as well as the older congenital case in which the remaining right lung has undergone a marked compensatory dilatation, to demonstrate the fact that complete posterior displacement of the heart with a rotation of the mediastinal vessels to the left due to compensatory dilatation of the remaining right lung is not incompatible with at least three decades through vigorous youth, adolescence, and at present healthy, hard laboring, adult life. To say what the longevity of these two patients would be is pure conjecture, but there is nothing to indicate that they will not survive to their normal expectancy. Their span of life will exceed, in all probability, the normal life expectancy of the average person operated on for a tumor of the lung; for, although these growths occur in young people, the great majority will be found between the fourth and the sixth decades. The remaining life expectancy would therefore be between three and one decades. In any event it would seem advisable to confine the primary operation to removal of the lung or parts thereof, leaving the need of further thoracoplastic procedures, not as a probability but as only a remote possibility, for the future. The necessity for this type of secondary operation would be determined by the patient's convalescence and postoperative activities.

To recapitulate, it may be said that resection of the entire lung seems to be a feasible operation which has proved itself worthy of a place among the recognized technically safe surgical procedures. Experience, although to a certain extent limited, thus far would warrant the conclusion that patients will survive this operation and be restored to their normal activity in a measure which is comparable not only in mortality but in the lack of postoperative incapacitation after operations performed for the removal of malignant visceral tumors elsewhere in the body.

RESULTS OF FIFTEEN CONSECUTIVE ONE-STAGE LOBECTOMIES FOR BRONCHIECTASIS*

E. J. O'Brien, Detroit, Mich.

FOR many years the need of a safe operation for the removal of parts or the whole of a lung has been recognized, but as yet no procedure or technic has been accepted as fulfilling all the requirements asked of it.

It is not necessary before this Society to go into the history of the numerous experiments on animals and the disappointment encountered when the results of this work were attempted upon the human being. This work was beautifully presented before this Society in the presidental address of Dr. Heuer[1] in 1934. Those were, as Heuer said, trying days for the surgeons and hazardous ones for the patient—so hazardous that for a time these efforts were discontinued.

In recent years, with the rapid development of thoracic surgery and a better understanding of thoracic disease, numerous workers in all parts of the world have again undertaken the problem, and today we appear to be on the threshold of an era in which we can offer those patients for whom nothing could be done in the past, a ray of hope for the future—these patients with chronic pulmonary suppuration or malignant disease which often made them outcasts of society or brought on an untimely death may now again resume their rightful places in society.

The problem, however, has not as yet been solved, for, while the operation has been made relatively safe, there still exists a serious controversy as to the relative merits of the one- and two-stage operations. We owe a great debt to Dr. Lilienthal[2] for his courageous work, which was really the beginning, in this country, of the present attempt to make possible an operation which would be the culmination of these many years of discouraging efforts. To Brunn[3] really belongs the credit for the present technic of our one-stage operation, for, while various refinements have been added by Shenstone,[4] Edwards,[5] and others since he reported his small series in 1929, his fundamental principles have not been changed.

Alexander,[6] Sauerbruch,[7] and others have been rather reluctant to accept the one-stage procedure because of the dangers of hemorrhage

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Read before the Nineteenth Annual Meeting of the American Association for Thoracic Surgery at Rochester, Minnesota, May 4, 5, 6, 1936.

and persistent extensive empyema with bronchial fistula, and these men have perfected a two-stage operation which has proved very effectual and safe for the patient.

There can be no question, however, that the ideal operation is the one-stage procedure if the dangers previously encountered from its use can be avoided. It is most certainly less burdensome to the patient—requires less hospitalization and should provide a lower mortality rate, for it requires only one major operation instead of two, and eliminates the dangers encountered, between stages, from difficulty of expectoration because of pain and disturbed intrapleural pressures, etc. If also

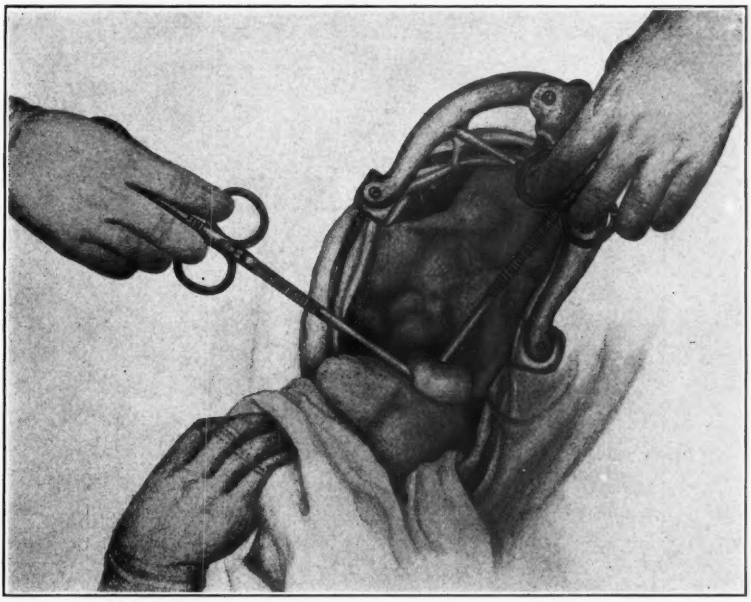

Fig. 1.—A drawing showing the lobe to be removed, isolated, and the hilum occluded between two lobectomy tourniquets (Bethune).

following a one-stage operation the remaining lobe becomes fully expanded and adherent to the stump before bronchial opening develops, there will be fewer persistent bronchial fistulas—which may require an additional major surgical procedure.

It is not my intention to present the solution to the present perplexing problems, but rather to offer my experience with the one-stage operation in fifteen consecutive lobectomies for bronchiectasis in the hope that something may be added to the present knowledge and technic.

The most serious disasters occurring following a one-stage lobectomy have been hemorrhage from the stump and empyema due to the de-

velopment of bronchial fistulas before the remaining lobe was fully expanded and adherent, and it was my thought that, by using additional precautions in ligature of the stump and facilitating more rapid expansion of the remaining lobe, these difficulties might be overcome. The operation is again merely a modification of the Brunn-Shenstone technic.

The thoracic cavity is opened through an incision posteriorly over the seventh or eight interspace. A small segment of two ribs is removed beyond the angle to permit better exposure when the rib spreaders are placed in position. It is my experience that there is

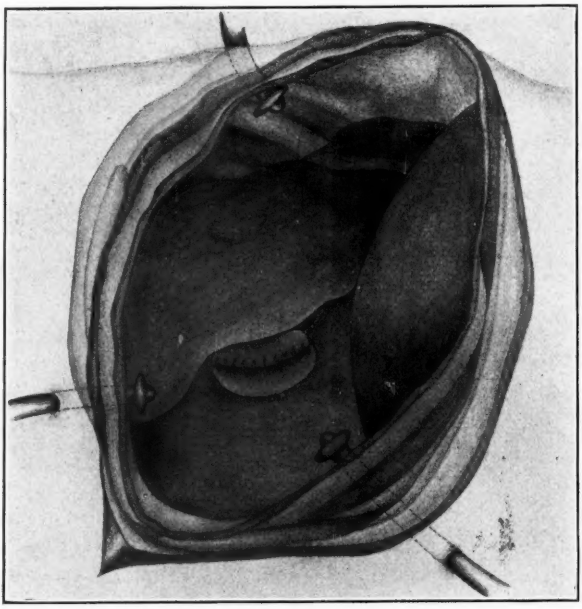

Fig. 2.—A drawing showing the stump closed and pleuralized and the three mushroom catheters for drainage in their respective places.

less postoperative pain when a segment is removed than when the ribs are merely cut. An attempt is made to place the proximal snare (Bethune's) around the hilus before manipulating the lobe so as to express as little secretion as possible into the bronchus. This can only be done, of course, if the lobes are comparatively free. If extensive adhesions are encountered, these must be freed and the lobe grasped with lung forceps while the two snares are put in place. The distal snare is placed far enough away so that the cuff, cut in the shape of a cone, will be large enough for careful and safe suturing (Fig. 1). The stump is then closed by several layers of No. 2 chromic mattress sutures and pleuralized as much as possible (Fig. 2). Simultaneous

with the removal of the proximal snare four strands of No. 2 chromic catgut are tied securely in the groove where the stump has been crushed while the snare was in place (Fig. 3). In order to ensure adequate drainage and rapid reexpansion of the remaining lobe three No. 32-34 Pezzar mushroom catheters are placed into the pleural cavity through

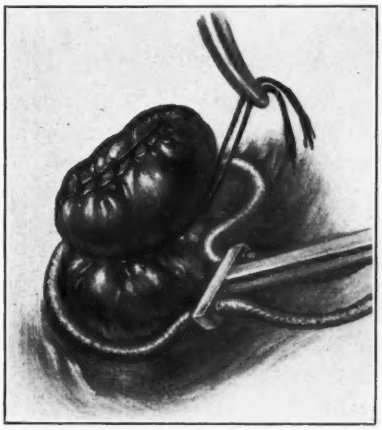

Fig. 3.—A drawing showing four strands of No. 2 chromic catgut securely tied in the bed left by the loosened snare.

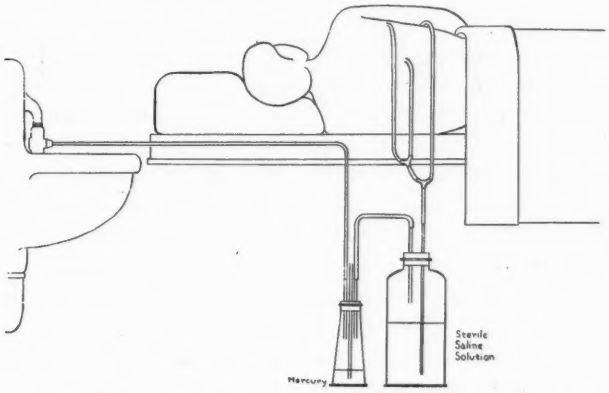

Fig. 4.—A sketch showing the tubes in place and the closed drainage suction apparatus set up.

stab wounds, and the chest is then closed tightly. One of the catheters is placed in the axilla, one above the diaphragm anteriorly, and one posteriorly at the stump (Fig. 2). Suction of approximately 15 cm. of water negative pressure is applied to the catheters immediately upon the patient's return to the room. The negative pressure is accomplished by the use of a mercury reduction chamber which is placed

in the circuit between the closed sterile drainage bottle and the water pump on the tap (Fig. 4). Negative pressure is maintained constantly for three weeks, at which time the tubes except the one at the stump are removed. The one at the stump is made an open drain. Early in this series it was my custom to rub the parietal and visceral pleural surfaces gently to facilitate adhesions, but I have discontinued this practice as unnecessary.

RESULTS

This report is based on the study of 15 patients with bronchiectasis who have submitted to lobectomy. The average age for the group was 27 years and 2 months; the youngest patient was 15 and the oldest 45 years. In four instances the disease was bilateral and in 11 unilateral. Where the disease was unilateral, it was confined to one lobe in 7 patients and to more than one lobe in 4.

In 6 instances the disease was of the saccular type and in 9 instances cylindrical. In 9 patients the lobe removed was of normal size, and there were 5 in which the lobe was atelectatic; in one patient a previous thoracoplasty had been done.

There was one death. This occurred on the fourteenth postoperative day of what clinically was a pulmonary embolus and could not be attributed to a one-stage operation. This patient had had a previous tuberculosis. It was felt, however, that this in no way contributed to his death.

The bronchial stump opened in 7 patients at an average of 11.9 days postoperatively; the shortest time was 7 days, the longest 17 days. Closure of the fistula occurred in from a few days to several months. No permanent fistulas which required treatment have remained. In 8 patients there was no evidence of bronchial opening.

A small empyema occurred about the stump in all patients. In 3 it was necessary to institute wider drainage; one of these required a small modified Schede operation; one required simple rib resection; and the third had a small foreign body type of empyema due to a piece of necrotic rib within the pleural cavity.

The lung was fully expanded in twenty-four hours in all patients except one. Here a tear in the lung at the time of operation prevented a complete expansion. In a few instances in which x-ray films were made as early as five hours after operation, the lung was completely out to the chest wall.

It was necessary to aspirate only 4 times. In one patient a single catheter was used, and air and subsequently fluid were trapped at the apex. The remaining aspirations consisted of a single time for small (25 to 50 c.c.) accumulations of fluid at the costophrenic angle. It has subsequently been found that it is unnecessary to aspirate these.

TABLE I

RÉSUMÉ OF CASES

NAME	BRONCHUS OPEN	ASPIRATION	TUBES REMOVED	SUBSEQUENT OPERATION FOR CHR. EMPYEMA	TYPE OF LESION	REMARKS
N. B.	No	No	Upper 18 days. Tube at stump at 4 months	No	Unilateral saccular aerated lobe	
M. S.	No	No	Upper 20 days. At stump 45 days	Empyema re-formed, rib resection, tube removed 2½ months	Unilateral saccular in lingula and lower	
M. M.	14 days	No	20 Tube at stump 5 months	No	Bilateral cylindrical aerated lobe	Fistula closed spontaneously 4 months
M. M.	No	Yes	Tube at stump 3 months	No	Unilateral cylindrical atelectatic lobe	1 catheter used, air trapped at apex
M. C.	7 days	Once	Upper 28 days. Tube at stump 6 months	Piece of necrotic rib removed	Cylindrical atelectatic M. and L. lobes	Subcutaneous emphysema. Fistula closed 5 months
T. S.	13 days	No	Upper 2 months. At stump in place when last seen	No	Bilateral saccular aerated lobe	Fistula open when last seen 3 months postoperative
D. K.	No	No	19 days upper. Tube at stump 6 weeks	No	Unilateral saccular small lobe	
M. K.	No	No	Upper 21 days. Tube at stump 6 weeks	No	Unilateral saccular U. and L. lobes	Previous thoracoplasty. 2 tubes used
N. J.	10 days	Once	Upper 4 weeks. Tube at stump 2 months	3 ribs resected. Fistula present. Closed 5 months	Unilateral cylindrical aerated lobe	
M. S.	No	3 times	No drainage	No	Unilateral M. and L. lobes atelectatic	
T. A.	7 days	No	Not removed	Patient died on 14th day of pulmonary embolus (?). No autopsy	Bilateral cylindrical atelectatic lobe	Subcutaneous emphysema
C. R.	17 days	2 times	Upper 23 days. At stump in place	No	Bilateral saccular aerated lobe	
L. L.	14 days	No	1 tube used 3 months	No	Unilateral cylindrical aerated lobe	
A. L.	No	No	Upper 21 days. Tube at stump 6 weeks	No	Unilateral cylindrical aerated lobe	
E. H.	No	No	Tube still in place	———	Unilateral cylindrical atelectatic lobe	Previous tuberculosis

No bleeding from the stump was encountered. On several occasions in which dense adhesions had bound the removed lobe to the chest wall, the drainage for a few hours was deeply blood stained, but no evidence of hemorrhage from the clinical standpoint was present. The patient previously cited, in whom the lung was torn at the time of operation, bled rather freely for several hours. Blood transfusions and intramuscular fibrogen, however, were given and the hemorrhage stopped.

Subcutaneous emphysema developed in two instances; in one the tube to the anterior part of the chest became stopped by the elevated diaphragm and the pocketed air escaped into the subcutaneous tissue. In the other patient a rent in the lung sealed to the chest wall and pumped air into the subcutaneous tissue.

DISCUSSION

It is hoped that the results here recorded may be added to the experiences of Brunn, Shenstone, and others to show the one-stage lobectomy to be a safe procedure. I have come to believe after a careful observation of the method that two factors used in this work have added to the factors of safety. The ligature added to the Brunn-Shenstone type of stump closure minimizes the possibility of hemorrhage. It may be contended by some that the presence of the ligature makes more difficult any surgical closure of the stump, should this be necessary. This may be true, but it is felt that the added precaution against hemorrhage and too early opening of the bronchus greatly outweighs this possibility. The relatively low instance of open stumps and the absence of hemorrhage would indicate that the ligature does not cause necrosis as is feared by some, and the stump I have been able to investigate showed no evidence of it.

The use of a constant low negative pressure suction to reexpand the lung rapidly and to keep it reexpanded cannot be spoken of too highly. The absence in this series of generalized empyemas attributes to its success.

It will be noted that a relatively large number of these patients had bilateral disease. In several of these I am contemplating removal of the diseased lobe on the opposite side. While it is true that the presence of bilateral disease complicates the postoperative course, the frequent and timely use of the bronchoscope or intratracheal catheter to remove secretions greatly lessens the postoperative hazards in these patients. To turn away the patient with bilateral bronchiectasis as inoperable is depriving many patients of their only hope of regained health. In several instances in which the disease was bilateral and the worst side was removed, marked improvement has been seen and the patient has decided that further surgery is not needed.

If bilateral operation is considered, it is important to determine whether the diseased lobes are air containing or collapsed. The patient with a small collapsed lobe, as a rule, notes no impairment of respiration following lobectomy; while the patient with a large fully aerated lobe may experience some transitory respiratory difficulty. Bilateral lobectomy where both lower lobes are functioning might offer serious embarrassment, while if collapsed for probably a long time no serious change should be noted.

CONCLUSIONS AND SUMMARY

The problem of one-stage lobectomy has been discussed.

A modification of the present methods has been offered, and the usefulness of postoperative negative pressure suction has been described.

It is felt that a one-stage operation which overcomes the objection to the procedure is superior to the two-stage procedure.

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LOBECTOMY AND PNEUMONECTOMY IN BRONCHIECTASIS AND CYSTIC DISEASE

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THE operations of lobectomy and pneumonectomy for bronchiectasis that form the basis of this report were performed during the years 1929-1935 (Tables I, II, and III). This period has been noteworthy for the revival of lobectomy and the introduction of total pneumonectomy in the treatment of lung suppuration.

TABLE I

LOBECTOMY AND TOTAL PNEUMONECTOMY FOR BRONCHIECTASIS AND CYSTIC DISEASE
DEC. 1, 1929—APRIL 1, 1936

	CASES	DEATHS
Lobectomy		
Exteriorization	2	0
One stage	18	0
One stage (bilateral)	1	0
Two stage		
(completed)	19	1
(first stage only)	7	1
Pneumonectomy		
One stage	1	0
Two stage	1	1
	49	3

Case mortality 6.1%

TABLE II

LOBECTOMY FOR BRONCHIECTASIS AND CYSTIC DISEASE

CASES	DEATHS	CASE MORTALITY
	Completed Lobectomies	
40 (one bilateral)	2	5.0%
	Lobectomies Completed by Methods Now Recommended	
38 (one bilateral)	1	2.6%

Last 30 successive cases (including one bilateral) completed without mortality.

TABLE III

BRONCHIECTASIS AND CYSTIC DISEASE. AGE DISTRIBUTION

YEARS	CASES	DEATHS
9-15	11	0
16-25	24	1
26-42	14	2

From the Surgical Services of the Massachusetts General Hospital.
Read before the Nineteenth Annual Meeting of the American Association for Thoracic Surgery at Rochester, Minn., May 4, 5, 6, 1936.

A turning point in the development of the operation on this continent came with the article by Harold Brunn published in 1929. Shortly thereafter came that simple but inspired contribution of Shenstone—the hilum tourniquet. These contributions to technics were preceded by the introduction of bronchography with iodized oil by Sicard and Forestier in 1922. The purely diagnostic value of bronchography is overshadowed by its aid to the visualization of pathology in mapping the extent and distribution of the disease.

The perfection of anesthesia technics, the recognition of the hazards of anoxemia, an increased use of bronchoscopy in diagnosis, and above all a dissemination of knowledge concerning the surgical physiology of the chest, have been important elements in the development of operations concerned with lung resection.

PREOPERATIVE MEASURES

Lobectomy in bronchiectasis is an elective operation from the standpoint of time; so careful attention may be directed toward preparing the patient for what is to be a strenuous ordeal at the best. A possible exception may be encountered when a patient is in the throes of severe recurrent hemorrhages. Under these circumstances the surgical program may need to be direct and immediate.

Time of Operation.—With few exceptions the lobectomies in this series have not been performed during the winter and the early spring. The limits of this "closed season" are arbitrary and depend somewhat upon the cycles of respiratory infections in the community. In general, operations have been discontinued after the middle of December and resumed the first of May. During these months patients with bronchiectasis usually experience an increase in cough and sputum and are subject to respiratory tract infections and attacks of pneumonitis. Routine throat cultures taken at this time of year show an increased incidence of pathogenic variants of the hemolytic streptococcus group. While no statistical evidence is at hand to support this policy, operations for bronchiectasis have been postponed unless urgent indications were present.

Bronchoscopy.—Diagnostic bronchoscopic examination should invariably precede lobectomy. In many of our patients treatment by bronchoscopic aspiration has been carried on at frequent intervals over a period of months. In certain instances a reduction in the amount of sputum and a disappearance of its foul odor have been favorable accomplishments, but I have not been impressed by any greater efficacy of drainage by bronchoscopy over drainage by postural methods alone if the latter program is carried out persistently and conscientiously.

Phrenic Paralysis.—In twenty patients a preliminary crushing of the phrenic nerve on the diseased side has preceded the lobectomy (Table

IV). Trial intervals of from four days to six months or more elapsed before lobectomy was performed. If allowances are made for the seasonal variation in the symptomatology of the disease, no effects either beneficial or deleterious have been observed. I have, therefore, ceased to recommend phrenic paralysis as an independent therapeutic procedure in bronchiectasis or to advise it as a preliminary step in the

TABLE IV

RESULTS OF PARALYSIS OF THE PHRENIC NERVE IN BASAL BRONCHIECTASIS. 20 CASES

INTERVAL OBSERVED	NUMBER OF CASES	EFFECTS NOTED
4-14 days	5	None
1-3 months	6	None
3-6 months	5	1 patient improved coincident with summer 1 patient temporary improvement 1 patient slight improvement
Over 6 months*	4	None

*Paralysis in all cases was produced by crushing.

surgical program. It may be worthy of a trial in patients with severe hemorrhage in whom operation must be postponed. Phrenic paralysis induced from within the chest in conjunction with the operation of lobectomy will be discussed below.

Artificial Pneumothorax.—Four patients in this series were treated by artificial pneumothorax at some time preceding the lobectomy. In addition I have had the opportunity to observe two patients in whom this treatment was prolonged over a considerable period of time. In but one instance has a real reduction in sputum or cessation of hemorrhages resulted even though excellent collapse has been obtained. The single patient who showed improvement has returned to almost the same condition as formerly following reexpansion of the lung at the end of four years. I can recognize no real place for the treatment of bronchiectasis by artificial pneumothorax; although, if I were faced by a severely hemorrhaging patient, I would be willing to try it. It is possible that artificial pneumothorax might be effective during the subacute pneumonic phase that may at times be recognized early in the developmental stages of certain cases.

I have had no experience with artificial pneumothorax as a direct adjunct to the operation, either to produce pleural adhesions by thoracoscopic methods or to promote an immunizing pleural reaction.

Postural Drainage.—All the patients in this series have received the benefits of postural drainage over prolonged periods of time prior to operation. It is an essential part in the program and must be carried out with particular emphasis during the days immediately preceding surgical intervention.

General Measures.—Surgeons accustomed to handling patients with pulmonary tuberculosis need not be educated in the value of rest and

supportive measures in the preoperative program. Patients with bronchiectasis will frequently respond to a sanatorium regime exactly as a case of chronic pulmonary tuberculosis by showing a gain in weight, a reduction in cough and sputum, and a subsidence of fever. I have been particularly impressed by the response of children to such treatment. There is no real evidence at hand, however, that demonstrates an actual regression in the pathology of the diseased lung. At the North Reading State Sanatorium the efficacy of such "cures" has been tested by postponing operation and allowing the child to return home. In every instance in well-developed cases of the disease the gains made in the sanatorium have been lost with the return of the patient to his home environment. It is important not to be misled by the improvement that results from a carefully planned medical regime but to consider it as an adjunct to surgery rather than sufficient in itself. In the New England climate no method of treatment can be adequately evaluated until the patient has passed through the cycle of respiratory infections of the winter and spring months.

Accessory Nasal Sinuses.—Many of the patients have had numerous operations on the accessory nasal sinuses. In cases of well-established bronchiectasis no real benefit has been derived from these procedures. Bronchiectasis and sinusitis frequently go hand in hand, but no convincing evidence shows that one is the cause and the other the effect. It is true that areas of chronic pneumonitis are observed in certain patients with chronic sinusitis, and in such instances the eradication of a focus of infection in the nasal passages may be an important preventive measure. Treatment of sinus infection may precede lobectomy as a general measure if the sinuses are actually blocked and filled with pus. The eradication of chronic sinus infection in the presence of extensive bronchiectasis is a difficult or impossible achievement, and in the majority of instances lobectomy should precede any series of radical operations on the nasal passages.

TWO-STAGE LOBECTOMY

Anesthesia.—The responsibilities of the anesthetist are of equal magnitude to those of the surgeon during any major intrathoracic operation. Dr. Howard Bradshaw has personally supervised the anesthesia in the majority of the cases here reported. I am greatly indebted to him not only for perfecting the methods employed but for his skilled supervision in their application. He will discuss the subject in a separate communication. From the standpoint of the surgeon a method of anesthesia must be employed that permits an operation of precision to be carried out with deliberation. An anesthetic that leads to a race to complete the operation before the patient dies of asphyxia or drowns in his secretions will inevitably end in disaster.

The First Stage.—For the removal of a lower lobe, or the lower and middle lobes, the eighth rib is resected from its transverse process to the posterior axillary line. The pleural cavity is opened, and adhesions between the lobes and the parietes are divided. If firm and vascular adhesions bind the lobe to the diaphragm, the dissection will be facilitated by injecting the phrenic nerve with novocaine. It is readily identified on the lateral aspect of the pericardium. The results of careful inspection and palpation of the middle lobe on the right and the lingula of the upper lobe on the left are recorded to determine the extent of the operation at the second stage. If these areas are involved, they should be resected at that time. The pulmonary ligament is identified and divided toward the hilum to a point just below the inferior pulmonary vein. Quite constantly an enlarged lymph node is encountered just below this vein, and may be mistaken for it. If this node is present, the dissection is stopped at this level. An enlarged lymph node may also be encountered at the lower end of the pulmonary ligament. This is left in the mediastinum. The two leaves of the divided pulmonary ligament are sutured with fine silk on both mediastinum and lung to produce a smooth pleural surface. Fine silk stitch ligatures are used to control vessels encountered in the adhesions.

The parietal pleura is now scrubbed briskly with dry gauze particularly over the anterolateral aspect and in the costovertebral gutter to promote adhesions with the upper lobe. The chest is closed without any form of drainage. If the patient has a considerable amount of sputum, a large pneumothorax is deliberately left in order to keep the lung collapsed during the early postoperative days. In any event, the pressures should be adjusted on the negative side in order to prevent chest wall emphysema.

A transfusion is given routinely, although it is unusual to see urgent indications for restoration of blood volume. The loss of plasma from the traumatized pleura in the immediate postoperative period will be comparable to the loss from a surface burn of similar area. A transfusion anticipates this loss of blood volume. The patient is placed in an oxygen tent on return to the ward. Aspiration of fluid and air from the chest is indicated by a shift of the mediastinum and respiratory distress. Frequently it is not necessary. In a few instances a low grade fever has persisted for two or three weeks following the first stage operation.

The Second Stage.—The chest is opened by excising the cutaneous scar and resecting the seventh rib. The lobe is separated from its bed of adhesions and its hilum developed. Tourniquets are placed at the hilum, and the lobe is amputated between them with heavy scissors. It is important to grasp the substance of the stump with hemostats during the amputation rather than to depend upon the tourniquet alone. I

have preferred to accept the hazards of soiling the field from the opened bronchi rather than employ a gauze or rubber pack that might obscure the hilum should the tourniquet slip.

Bronchi or blood vessels that may be identified in the stump are secured individually with stitch ligatures of chromic catgut. Deep sutures are then taken further to obliterate vessels and bronchi. The ends of the sutures are temporarily grasped with hemostats to steady and maintain control of the stump. The tourniquet is now loosened to allow the stump to fill with blood and then reapplied for a brief interval to allow closure of small vessels by coagulation. The tourniquet is again loosened and the stump inspected for bleeding vessels. It is often necessary to place additional sutures or ligatures at this time. When assured of complete hemostasis and complete closure of all bronchi, a running suture of No. 0 chromic catgut is employed to unite the pleural edges of the stump. At times the apex of the lobe which has been cut tangentially may be turned downward as a flap. Early in the series, an effort was made to bring the stump into contact with the upper lobe, but this is no longer done.

Dependent drainage is provided by a large catheter, and the major incision is closed tightly. Transfusion and oxygen tent are used as in the first stage.

ONE-STAGE LOBECTOMY

If a one-stage procedure is contemplated, the seventh rib is resected. If the decision to remove the lobe is made after the chest has been opened through the bed of the eighth rib, the operation may frequently be completed by this approach or the incision extended by severing the vertebral end of the seventh rib. It is particularly in the densely adherent cases that a one-stage procedure will be undertaken. Great pains must be taken to control completely the bleeding points on the chest wall, the diaphragm and the mediastinum. If there are many bleeding points or areas of persistent oozing, the phrenic nerve is crushed about one inch above its contact with the diaphragm as a further safeguard for the postoperative period.

In only one case of lobectomy has drainage been omitted following amputation of the lobe. This was a child with cystic disease accompanied by no apparent sputum. A preliminary artificial pneumothorax was induced, and 15 c.c. of the patient's blood injected into the pleural cavity to initiate an inflammatory reaction. The operation was carried out in one stage without obvious soiling of the pleura. An empyema developed postoperatively requiring drainage on the eighth day.

MIDDLE LOBE RESECTION

In 6 cases the middle lobe has been removed with the lower lobe. It can usually be mobilized so that a single tourniquet can be employed at the hilum. In one instance due to an incomplete fissure between upper

and middle lobes, separate tourniquets were employed. In cases with firm adhesions the freeing of the middle lobe from the cardiophrenic fat pad and the pericardium presents unusual difficulties. In 3 cases the lingula of the upper lobe has been removed with the left lower lobe.

In 3 cases the middle lobe was the only area involved (Fig. 1). The technic of removing the middle lobe alone is similar to that employed for the lower lobe except that an anterolateral approach through the bed of the fifth rib is employed. Convalescence after the removal of the middle lobe alone has been attended by partial atelectasis of the lower lobe with continued cough and sputum for three to five weeks. I have interpreted this complication as a partial obstruction of the bronchus

Fig. 1.—Bronchiectasis sharply limited to only a portion of the middle lobe. Usually this lobe is totally involved if at all.

of the lower lobe from the adjacent inflammatory reaction in the healing middle lobe stump. The ultimate results have been excellent, however, and the lower lobes have completely expanded.

POSTOPERATIVE COURSE

Hemorrhage.—In no instance has there been evidence of postoperative hemorrhage from the hilum of the lobe. In 4 cases serious hemorrhage occurred from vessels in the chest wall or mediastinum. In 1 of these the hemorrhage must be considered as a contributory cause of death. Hemorrhage was also a contributory cause of death in the fatal case of total pneumonectomy.

CASE 1.—No. 332939. At a first-stage operation the lower lobe was dissected from dense adhesions to the diaphragm. No postoperative transfusion was employed. During the early morning of the next day the pulse rose abruptly and the blood pressure fell. Emergency transfusion was given restoring the blood pressure to a normal level at which it remained until death. The pulse rate continued rapid; 700 c.c. of blood was removed by aspiration of the pleural cavity. On the evening of the following day the patient became dyspneic, pale, and unconscious. Pulmonary edema and respiratory embarrassment were the immediate causes of death. Autopsy showed some blood in the pleural cavity and a hematoma dissecting the tissues of the mediastinum. It appeared to originate in the adherent area on the upper surface of the diaphragm. This patient did not die directly of acute blood loss

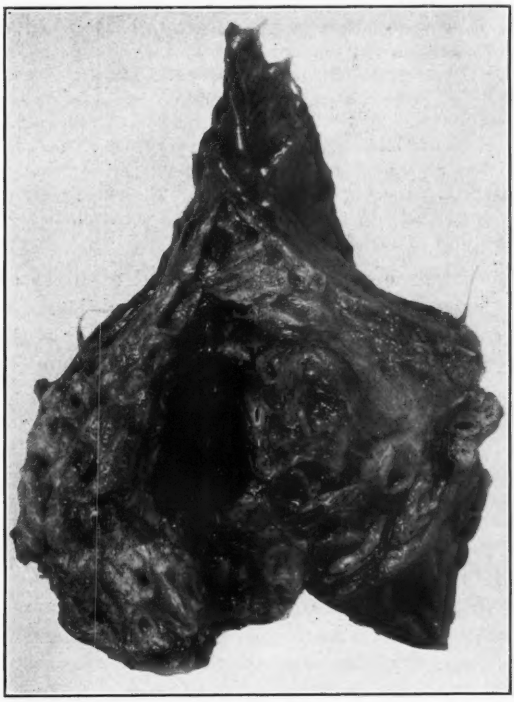


Fig. 2.—Left lower lobe containing an encapsulated gauze sponge. Tracheotomy at age one and one-half years followed by rib resection for empyema. Second thoracotomy at age sixteen years. Treated for several months by bronchoscopic aspiration preceding lobectomy at age of twenty-five years.

but of the pulmonary edema that followed it. Intravenous infusions of saline solution were thought to have been a contributing cause of the pulmonary edema.

CASE 2.—No. 344456. The second stage of a lobectomy was performed without incident. At 9 P.M. the pulse rose to 140 and 350 c.c. of blood drained from the chest within the space of an hour. Suction was discontinued, but the tube was left open under a water seal. At midnight 200 c.c. more blood flowed into the drainage bottle. The patient appeared apprehensive and the pulse was weaker. Blood pressure dropped from 106 mm. to 80 mm. of mercury. The pulse improved somewhat in quality, but a steady trickle of blood ran from the tube. At 3 A.M. the

patient was given a transfusion and the wound was opened. A large clot filling the cavity was evacuated. The hilum area was carefully inspected but no bleeding was found. There were two or three areas on the inner aspect of the chest wall in the incision that were oozing slightly. The chest was closed again and convalescence was without further incident.

CASE 3.—No. B.M. 20369. A densely adherent lobe was removed in a one-stage operation from a patient who had previously had three thoracotomies for empyema years before. The lobe contained a piece of gauze drain that was so deeply embedded that it was not discovered until the lobe was sectioned (Fig. 2). The patient was in excellent condition during the night following operation, draining 100 to 150 c.c. bloody fluid. After changing his bed at 10 A.M. the following morning, 500 c.c. of blood suddenly drained from the catheter. The course thereafter was typical of continuing hemorrhage—progressive pallor, thirst, falling blood pressure, and rising pulse. Suction was removed at 10:15 A.M. Blood continued to trickle from the tube. The tube was clamped at 1:15 P.M. At 2 P.M. 500 c.c. of air was injected to produce a positive intrathoracic pressure. The pulse became paradoxical from cardiac tamponade. At 4 P.M. the chest was opened following a transfusion. About 500 c.c. of clotted blood was removed from the cavity. A small but definitely bleeding vessel was discovered on the surface of the pericardium. This was controlled with a stitch. The hilum area was dry. The phrenic nerve was crushed just above the diaphragm. The wound was closed, a second transfusion was given, and convalescence was without further incident.

The sudden drainage of a quantity of blood from the catheter is a disconcerting incident but if unattended by clinical signs of hemorrhage may be due to the emptying of the pleural cavity of the accumulation of several hours. Such an event is illustrated by the following incident.

CASE 4.—No. 336952. The lower and middle lobes were removed at a one-stage operation from a densely adherent pleural space. There was no drainage during the night. Early the following morning 500 c.c. of very bloody fluid drained within a space of five minutes. Suction was discontinued and the tube clamped. The patient was moved to the operating room for observation. As his pulse and blood pressure remained constant, interference was not indicated. Further convalescence was uncomplicated.

Drainage.—The catheter used as drainage tube is connected with a suction apparatus and a negative pressure of 3 to 6 cm. of water maintained. The amount of drainage varies in different cases but usually 5 to 10 ounces of bloody fluid are collected during the first twenty-four hours. The drainage does not become frankly purulent until the third or fourth day. Suction is continued until the cavity is of minimal size, and then the sinus is handled as in any case of empyema.

Bronchial Fistula.—A bronchial fistula appears at some time in almost every case. It in no way complicates the convalescence and invariably closes. In the surgery of the lung, bronchial fistulas that fail to close are in areas of lung closely in contact with the chest wall. For this reason extensive thoracoplastic procedures bringing the chest wall near the hilum, and conversely, lobectomies of the exteriorization type that bring the stump of the lung to the chest wall, are liable to be complicated by persistent fistulas.

THE TWO-STAGE OPERATION WITH DELAYED SECOND STAGE

The primary goal of a two-stage operation is the obliteration of the pleural space before cutting across the hilum of the lobe and its pus contaminated bronchi. Other indications will be encountered from time to time and are summarized in Table V. The pendulum is definitely swinging toward the one-stage procedure in many clinics, and it may well come about that the indications for dividing the operation will become fewer in number. There will probably always be some indications for its use. The real point at issue is whether the operation of election is a one- or a two-stage procedure when no adhesions bind the lobe which is to remain to the parietal chest wall.

Although I am prepared to reshape my views as to the choice between a one-stage operation and a two-stage operation, once having elected a

TABLE V

INDICATIONS PROPOSED FOR CHOICE OF OPERATION

ONE STAGE	TWO STAGE
Obliterated pleural space or strong adhesions binding upper lobe to chest wall	Adults with free pleural space
Children	Febrile patients with active pneumonitis
Middle lobe resections	Patients treated for a prolonged period with artificial pneumothorax and not having an adherent upper lobe
Severe hemoptyses	Bilateral cases with free pleural space
Lobar atelectasis particularly if upper lobe does not show emphysema	
Draining thoracotomy sinus or bronchocutaneous fistula	
Cutting into infected lung when freeing adhesions	
Bronchial stenosis	

two-stage procedure, I have no hesitancy in advocating what may be termed a "delayed second stage." By a "delayed second stage" is meant postponement of the actual removal of the lobe for at least six weeks after the first-stage operation. The advantages of this procedure are many and are also to be weighed in making the initial decision between a one- and two-stage operation.

In addition to the obliteration of the pleural space with the resulting localization of the empyema that follows the actual lobectomy, a real improvement in the status of the patient follows the first-stage operation in a majority of instances. These results are recorded in Table VI and again summarized in Table VII. So far as possible these "results" have been surveyed with due allowance for seasonal variation in the severity of the symptoms of the disease. The fact remains that a considerable number of patients approach the really hazardous step of the surgical program in a much better condition than the ordinary methods of preoperative care can bring about. Although my personal experience with

TABLE VI

RESULTS OF FIRST STAGE OF TYPICAL TWO-STAGE LOBECTOMY

PATIENT	LOBES INVOLVED	LOBES ISOLATED	INTERVAL UNDER OBSERVATION	SEASONS	RESULTS
T. H.	L. L.	L. L.	102 days	Spring	Sputum reduced 180 c.c. to 75 c.c. Weight gain 1½ lb.
C. G.	L. L.	L. L.	86 days	Summer	Sputum reduced. Frequent hemorrhages abolished. Weight loss 2 lb. Real gain in strength.
M. D.	R. L.	R. L.	79 days	Summer	Sputum reduced. Purulent character changed to mucoid. Weight gain 4 lb.
D. L.	R. L. and M.	R. L. and M.	101 days	Summer	Sputum reduced 240 c.c. to 15 c.c. Cough greatly diminished. Weight gain 7½ lb.
A. V.	L. L.	L. L.	348 days	All	Sputum reduced 120 c.c. to 60 c.c. Cough and sputum absent during summer. Sputum during subsequent winter mucoid rather than purulent. Weight loss 3½ lb.
S. K.	L. L. and lingula	L. L. and lingula	79 days	Spring	Temporary diminution cough and sputum. Weight gain 1 lb.
S. S.	L. L.	L. L.	285 days	Winter, spring, summer	Sputum reduced 105 c.c. to 30 c.c. Cough decreased. Immediate weight gain 23 lb. Unexplained loss during summer to net weight gain 2 lb.
G. W.	L. L. and lingula	L. L. and lingula	59 days	Spring	No change.
E. H.	L. L. and lingula	L. L. and lingula	135 days	Summer	Sputum reduced 60 c.c. to 8 c.c. Cough decreased. Weight gain 3 lb.
E. P.	L. L.	L. L.	120 days	Fall and winter	Sputum reduced 90 c.c. to 30 c.c. Cough decreased especially at night. Weight gain 1 lb.
R. C.	L. L.	L. L.	52 days	Summer	Sputum 30 c.c. abolished. Cough abolished. Weight loss ¾ lb. (Gain of 5½ lb. in month preceding second stage.)
C. M.	L. L.	L. L.	222 days	Fall, winter spring	Cough diminished. Complete cessation of weekly hemoptysis. Weight same.
I. E.	R. L. and L. L.	L. L.	200 days	Winter, spring	Cough same. Sputum reduced by one-half. (Note bilateral involvement.) Weight loss 10 lb.
M. M.	R. L.	R. L.	152 days	Winter, spring	Sputum same. Hemoptyses reduced in number and severity. Relief of chest pain. Weight gain 4 lb.
S. B.	L. L.	L. L.	107 days	Spring, summer	Sputum reduced 90 c.c. to 60 c.c. Completely abolished during first month. Weight loss 7½ lb.

TABLE VI—CONT'D

PATIENT	LOBES INVOLVED	LOBES ISOLATED	INTERVAL UNDER OBSERVATION	SEASONS	RESULTS
A. L.	L. L. and R. M.	L. L.	74 days	Spring	Sputum 30 c.c. abolished. Cough greatly improved. Weight same.
L. W.	L. L.	L. L.	118 days	Summer	Sputum 120 c.c. abolished. Cough abolished. Weight same.
E. P.	R. L.	R. L.	57 days	Fall	Sputum reduced 120 c.c. to 45 c.c. Weight gain 2 lb.
Patients Not Yet Subjected to Second-Stage Operation					
A. L.	L. L.	L. L.	9 months	Fall, winter, spring	Present status complicated by operations on nasal sinuses.
F. P.	L. L.	L. L.	5 months	Winter	Sputum reduced 120 c.c. to 60 c.c. Foul odor abolished. Weight gain 8 lb.
C. C.	R. L.	R. L.	2 months	Summer	Sputum unchanged. Cough diminished. Weight gain ½ lb. (Present status 9 mo. after operation unknown.)
J. S.*	L. L. and lingula R. M.	L. L. and lingula	16 months	All	Complicated by streptococcus empyema (see text). Healed. Sputum reduced 180 c.c. to 120 c.c. Weight gain 8 lb.
A. H.	R. L. and R. M.	R. L. and R. M.	27 months	All	Sputum 120 c.c. abolished. Frequent hemoptyses abolished. Weight gain 26½ lb. Complete symptomatic cure. (See text.)
E. D'L.	L. L. and lingula	L. L. and lingula	5 months	Winter, spring	Sputum same. Weight gain 3 lb.

*Second stage performed on April 24, 1936. Convalescence uneventful to date.

TABLE VII

SUMMARY OF TABLE VI. RESULTS OF FIRST STAGE ONLY. 24 CASES

SPUTUM			COUGH			HEMOPTYSES			WEIGHT*	
ABOLISHED	REDUCED	INCREASED	ABOLISHED	REDUCED	INCREASED	ABOLISHED	REDUCED	INCREASED	GAIN	LOSS
4	13	0	3	8	0	2	1	0	14	5

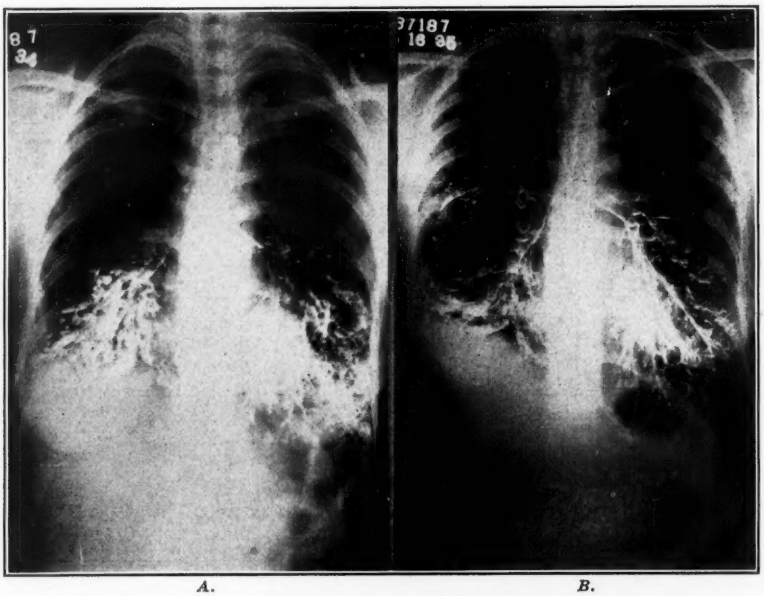
*Weights compared are (1) immediately preceding first stage and (2) immediately preceding second stage. If second stage has not been done, the present weight is taken.

the immediate second stage procedure advocated by Alexander has been limited, there are no published data that lead me to believe this is the case with his operation.

The underlying cause of this improvement is somewhat obscure and doubtlessly many factors are involved. Among these may be mentioned: (1) the release of firm adhesions binding the affected lobe to the costophrenic sulcus; (2) the temporary compression and collapse of the lobe by the residual pneumothorax and pleural effusion. The latter is pre-

sumably the cause of an immediate abolition of cough and sputum but not of a change that persists after the reexpansion of the lung.

We come back to the concept frequently reappearing in the literature that the placement of the lower lobe bronchial dilatations in a horizontal position rather than a vertical one aids in their drainage. X-ray films are reproduced in Fig. 3 of patient A. H. recorded as the next to the last patient in Table VI. This patient has obtained a complete symptomatic cure by a first stage operation. There is no cough, no sputum, a complete cessation of frequent hemoptyses, and a gain in weight of 26½ lb. This arrest in symptoms has persisted through all seasons of two years. Actual removal of the lobe has been indefinitely postponed.



A. *B.*

Fig. 3.—*A*, Preoperative film of bronchiectasis of right lower lobe. *B*, appearance two years after complete symptomatic cure by first-stage operation only.

The procedure described by Garré may well have evoked this principle, although the production of atelectasis and actual compression therapy were uppermost in his mind. The occasional beneficial results reported from phrenic paralysis have been attributed to this upward displacement of the lower lobe. At the second stage operation the involved lobe shows no more atelectasis than was present primarily. The costophrenic sulcus particularly in the posteromedial area is uniformly found obliterated, and as a consequence the lobe is found in a much higher position in the chest.

The disadvantages of a two-stage operation must be honestly faced in a critique of the procedure. Above all, is the hazard of a second major

operation. The risks of the anesthetic, of postoperative pneumonia, and of hemorrhage from the chest wall are real ones and in any considerable number of cases will be attended by a definite mortality rate. Adding 6 patients in whom a first stage has not as yet been followed by the removal of the lobe to the 19 cases that form the basis of this report, we can estimate these hazards in 25 patients. There has been one death—a mortality rate from the first stage alone of 4 per cent. It is fair to say that this death might well have occurred if the lobe had been removed at the operation. There has been one serious complication— a streptococcus empyema treated by catheter drainage with speedy recovery but actually endangering life and necessitating a protracted postponement of the actual lobectomy. In this patient a lymph node 2 cm. in diameter lay between the folds of the pulmonary ligament at its lower end. This was more closely attached to the lung than to mediastinal structures and was delivered with the lobe when the ligament was severed. It was removed for bacteriologic studies. A streptococcus empyema developed. This happening calls to mind the experiences reported by Auchincloss in which the removal of mesenteric lymph nodes was followed by streptococcus peritonitis. The lymph node itself gave no bacterial growth in either aerobic or anaerobic cultures.*

Although the total duration of the surgical program is prolonged by the two-stage procedure, the actual stay in the hospital is not greatly affected. The figures in Table VIII are of considerable interest. It is

TABLE VIII

POSTOPERATIVE HOSPITAL DAYS

	ONE-STAGE LOBECTOMY (19 CASES)				TWO-STAGE LOBECTOMY (18 CASES) (INCLUDING BOTH STAGES)			
Postoperative hospital days	Under 30 days	30-50 days	50-100 days	Over 100 days	Under 30 days	30-50 days	50-100 days	Over 100 days
Number of cases	3	5	9	2 (117 and 144)	0	9	8	1 (164)
	Average 59 days				Average 62 days (First stage 21 days) (Second stage 41 days)			

obvious that the number of postoperative days in the hospital cannot be compared on an absolute scale with those of any other clinic because the circumstances governing discharge from a hospital vary tremendously with local customs. The figures within the same institution comparing the stay following one program with that of the other will not be valid if one anticipates such a comparison when the patients are still under treat-

*The second-stage operation has been completed on this patient with removal of the left lower lobe and the lingula of the upper lobe. The pleural adhesions were dense in the region of the chest wall incision but presented no unusual difficulties. Convalescence has been uneventful to date.

ment. Quite a different showing might be made entirely unconsciously if one had the slightest prejudice for or against either procedure while the series was in progress.

The compilation of Table VIII was entirely an afterthought; so it represents the actual facts uncolored by any conscious or subconscious effort to prove that one method was better than the other.

Another disadvantage of the two-stage procedure is that a patient may refuse the second operation. This has not yet been encountered and can largely be avoided, at least in intelligent patients, by taking time to explain the program at the outset. If a patient obtains considerable relief following the first stage, he has added confidence in being completely cured; if he has no alleviation of symptoms and has been told that there was no reason to expect it, he is still eager to be relieved of his disease.

A question frequently asked about the delayed second stage operation is whether the adhesions that follow the traumatic pleuritis present unusual difficulties after a delay of weeks or months. The answer to this not only is found in the actual observation that they do not, but also can be understood if reference is made to the general principles of the healing processes in the body. Adhesions following a single traumatic insult to serous surfaces are composed of delicate connective tissue and tend to decrease in firmness with time rather than increase. Firm vascularized adhesions are produced by persistent and long continued infection. The thickened adherent pleura of a chronic empyema is a result of long continued infection. Adhesions encountered a year or so after a rapidly healing acute empyema may already be light and filmy. In bronchiectasis firm and vascular adhesions are not infrequently found binding inflamed areas of the lung to the parietes. These are disposed of at the first stage operation. The adhesions resulting from the trauma induced at that operation are invariably light and usually nonvascular.

If an interval of many months is allowed to elapse between stages, particularly if cough and sputum are persistent, it is quite true that firm adhesions may re-form as a result of the infection in the lung and to some extent reproduce the condition found at the first stage. The original adhesions, however, are usually the result of infection of many years' duration with recurring flare-ups of pneumonitis or invasion of the parenchyma by actual abscess formation; so a delay even of many months will not see their re-formation. Usually the lobe at the second stage can be mobilized rapidly without recourse to sharp dissection, and rarely are vessels encountered that require ligation. The adhesions that are difficult to deal with in the operation of lobectomy are those encountered in first mobilizing a lobe in which there is active parenchymatous infection.

We have learned to avoid the introduction of chromic catgut ligatures within the pleura at the first stage as the exudative healing reactions evoked, led to small areas of dense adhesions. Fine silk ligatures are employed and any considerable areas of denuded pleura repaired by silk sutures.

It has been stated that when the upper lobe is bound to the chest wall by adhesions it may not expand to obliterate the empyema cavity. These fears would seem to be groundless, as ordinary encapsulated empyemas invariably heal under these conditions provided dependent drainage is established. Only one instance of persistent empyema has occurred in this series, and that followed a one-stage operation in a patient treated for several weeks with an artificial pneumothorax to control bleeding. Although the lung had been reexpanded prior to lobectomy, the upper lobe was not adherent and failed to reexpand after the operation. The empyema cavity was closed by accessory operations. In a second patient who had received prolonged artificial pneumothorax treatment the upper lobe was similarly nonadherent, and its surface was observed to be thickened by connective tissue proliferation. The operation was divided into two stages with successful production of adhesions, and convalescence was uneventful. Prolonged pneumothorax therapy is therefore considered to be an indication for the two-stage procedure if the upper lobe is not adherent to the chest wall.

BILATERAL CASES

No hesitancy is felt in embarking on a surgical program in bilateral cases, although it has been carried to its completion in only one patient. If the disease is minimal on one side and extensive on the other, complete symptomatic cure may be effected by the removal of the chief focus of disease. With well-developed lesions in both lungs the feasibility of surgical attack must be a matter of judgment in individual instances. Three patients with extensive involvement of both lower lobes have been subjected to the removal of one without incident. The x-ray film of one of these patients is reproduced in Fig. 4 to illustrate the type of disease under discussion. As expected, the volume of sputum has been cut in half, and in one of these cases a recurring hemoptysis has ceased. All three patients are eager to have the lobe on the other side removed, and I know of no anatomic or physiologic contraindication. These will be undertaken in the near future.*

A brief account of the single case already subjected to a bilateral lobectomy is of interest because of an error that might well have been a serious one. The patient was a child in whom lipiodol films had

*Jan. 25, 1937. Five bilateral lobectomies have been completed, with one death.

clearly demonstrated atelectasis and bronchiectasis of the left lower lobe and extensive bronchiectasis of the right middle lobe (Fig. 5). It was planned to remove the left lower lobe first, and at a later date the right middle. On opening the left chest I was amazed and humiliated to find the "right" lung, due to a complete situs inversus. The diseased middle lobe was removed, and at a later date the "left" lower lobe was removed from the right chest. Fortunately the error in no way concerned the welfare of the patient; but, if the disease had been unilateral, such a mistake would have rested heavily upon one's conscience. In our own hospital this child had been examined by at least six physicians including medical consultants, had been fluoroscoped, and the x-ray films had been interpreted by the roentgenologist. The moral of this story is obvious. It is important to bear in mind as

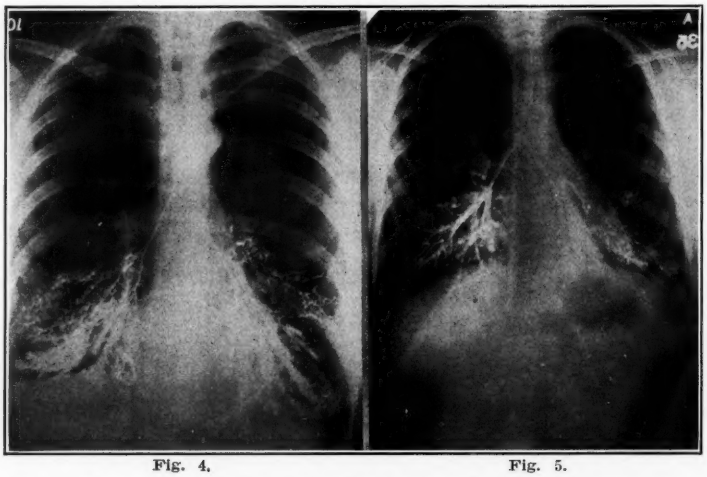


Fig. 4. Fig. 5.

Fig. 4.—Typical case selected for bilateral lobectomy. The left lower lobe has been removed by a two-stage operation.

Fig. 5.—Bronchiectasis of "right" middle lobe and "left" lower lobe with complete situs inversus. Bilateral lobectomy.

there is some evidence that the combination of situs inversus and bronchiectasis is encountered with greater frequency than can be explained by coincidence.

RESULTS

General Symptoms.—In estimating results it is obvious that the preoperative status of the patient should be taken into consideration, but space does not permit a detailed presentation of individual case histories. The important elements are the criteria used to determine operability. It is obvious that a low mortality rate and convincing end-results may be obtained in the treatment of any disease if only the favorable cases are selected for treatment. It is fair to state that in

our choice of cases from a larger group under observation, no patient has been rejected for whom lobectomy offered any reasonable hope of improvement. The patients rejected have usually been those with mild forms of the disease in whom the handicap seemed insufficient to warrant operation. Patients have not been operated upon during periods

TABLE IX

RESULTS

30 cases classified as cured. (Cough and sputum absent or minimal. No hemoptyses. Incisions healed. Normal activity. Includes 1 bilateral case and 1 total pneumonectomy.)

5 Cases Classified as Improved.

CASE	INTERVAL SINCE OPERATION	COUGH	SPUTUM	HEMOPTYSES	INCISIONS	NOTES
B.C.H.	6 years	0	0	Occas.	Minute bronch. fistula	Exteriorization lobectomy. Working actively at hard labor. Preop. sputum 450 c.c. foul.
333654	27 months	Slight	45 c.c. not foul	Occas.	Healed	60 c.c. foul blood-streaked sputum preop.
331308	9 months	Slight	4 c.c.	Occas.	Healed	Normally active life.
339545	17 months	0	0	Occas. 15 c.c. with eta.	Healed	6 years preop. completely incapacitated by life endangering hemorrhages.
348594	4 months	Slight	60 c.c.	0	Healed	90 c.c. bloody sputum preop. known tuberculous background.

5 Cases of Multilobar Involvement Classified as Improved.

CASE	LOBES INVOLVED	LOBES REMOVED	NOTES
312887	L. L., L. U., and R. M.	L. L.	Reduction of sputum bringing real palliation in advanced case.
B.M. 15712	R. L. and L. L.	L. L.	50 per cent reduction of sputum. Cessation of hemoptyses.
346260	R. L. and L. L.	R. L.	50 per cent reduction of sputum. Foul odor abolished. Works 7 days a week.
344456	L. L. and R. M.	L. L.	No recurrence of hemorrhage. Sputum abolished but recurred following acute pneumonitis of right lung.
269429	R. L. and M., L. L.	R. L. and M.	Bronchial fistula patent 5 mo. after operation. Sputum reduced over 50 per cent.

3 Operative Deaths (Including 1 Total Pneumonectomy).

CASE	NOTES
322393	Age 35. R. L. and M. involved with small focus contralateral disease. Second stage performed 26 days after first stage (1932). Death from pneumonia.
332939	Age 30. Death following first-stage operation. Discussed in text under Hemorrhage.
298720	Extensive unilateral cystic disease under observation many years. Total pneumonectomy attempted but abandoned after resection of middle and lower lobes. Death from pneumonia. Contributory causes were hemorrhage and shock.

6 Cases With First Stage Operation Only. Summarized in Table VI.

49 cases of bronchiectasis and cystic disease subjected to lobectomy or total pneumonectomy Dec. 1, 1929, to April 1, 1936.

of active pneumonitis if the condition was recognized. Recurring hemorrhages have been considered an indication for surgical intervention rather than a reason for postponement. No case has been rejected because dense pleural adhesions were anticipated. Several patients had had preceding empyema or thoracotomy for drainage of the lung. During the past year cases with multilobar disease have been accepted, and these are included among the cases reported.

Thirty patients may be classified as cured of their disease. Cough and sputum are absent or very minimal. There have been no hem-

A. *B.*

Fig. 6.—*A* and *B*, postoperative lipiodol films showing residual bronchiectasis in stump of lobe; 40 c.c. sputum and small hemoptyses.

optyses subsequent to operation. Operative incisions are firmly healed, and the patients are leading normally active lives. Several of the male patients are engaged in hard manual work.

Five patients with frank bilateral bronchiectasis have shown the improvement that was expected from the removal of a single lobe. These are summarized in Table IX.

Five patients are classified as improved (Table IX). One of these was subjected to an exteriorization lobectomy in 1929. Very little of the lobe became necrotic, but the cough was entirely relieved and 450 c.c. of very foul sputum a day was abolished completely. A year

following the operation a pinpoint bronchial fistula developed in the scar. This is open only with the arm extended above the head and requires no dressing. On several occasions there has been a brisk hemorrhage from this minute opening.

Three patients have continued to have certain symptoms of the disease, although they are greatly improved. In two of these cases lipiodol injection shows an area of bronchiectasis in the stump of the lobe. Both were one-stage operations, but this fact is presumably unimportant. Postoperative lipiodol films of the more extensive of these cases are reproduced in Fig. 6. This patient had an active pneumonitis

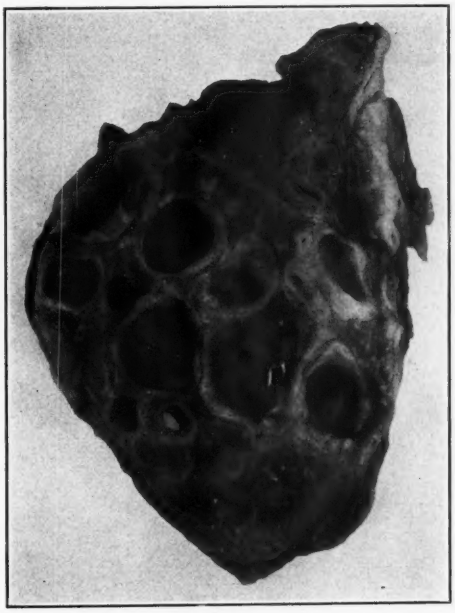


Fig. 7.—Cystic bronchiectasis associated with cicatricial stenosis of lower lobe bronchus of twenty-two years' duration.

of the middle lobe at the time lobectomy was performed, and difficulty was encountered in isolating the hilar region.

The fifth patient classified as improved has had an interval of only four months since operation and two months since a bronchial fistula has closed. It is hoped that she may be transferred to the "cured" group in the course of time.

Wound Healing.—Incisions and drainage tracts are firmly healed except in two cases. The patient with a minute bronchial fistula is described above. One other patient, a debilitated young woman with involvement of middle and lower lobes on the right and the lower lobe

on the left, was subjected to a one-stage removal of the right lower and middle lobes on Nov. 18, 1935. On April 8, 1936, the bronchial fistula was still open.*

CYSTIC DISEASE

The three cases classified as cystic disease presented unusual pathologic and clinical findings. The principles of surgical treatment are the same. Cyst formation in the lung that appears to be a true structural malformation may be closely simulated by cystic bronchiectasis associated with bronchial stenosis. The lower lobe shown in Fig. 7 was removed from a twenty-seven-year-old woman who had aspirated a

Fig. 8.—Cystic disease of left lower lobe.

collar button at the age of four years. At the age of thirteen years the foreign body was removed by Hedblom through a thoracotomy incision. Cicatricial stenosis of the lower lobe bronchus caused retention of secretions with very foul sputum. It was impossible to fill this lobe with lipiodol by the bronchial route. This case is termed cystic bronchiectasis, and the developmental pathology appears comparable to that of an infected mucocele in other regions of the body.

In contrast, Case No. 341724 is clearly that of a cystic lower lobe due to malformation of the bronchial tree. The large multilocular infected cyst (Fig. 8) had been drained three years before, but of course the

*The fistula closed in June, 1936.

sinus failed to close. On removal of the lobe the bronchial tree was found represented only by one bronchus not over 1.5 mm. in diameter (Figs. 9 and 10).

The problem of differentiating cystic disease from the adult type of tuberculosis in a girl of twelve years was presented by Case No.

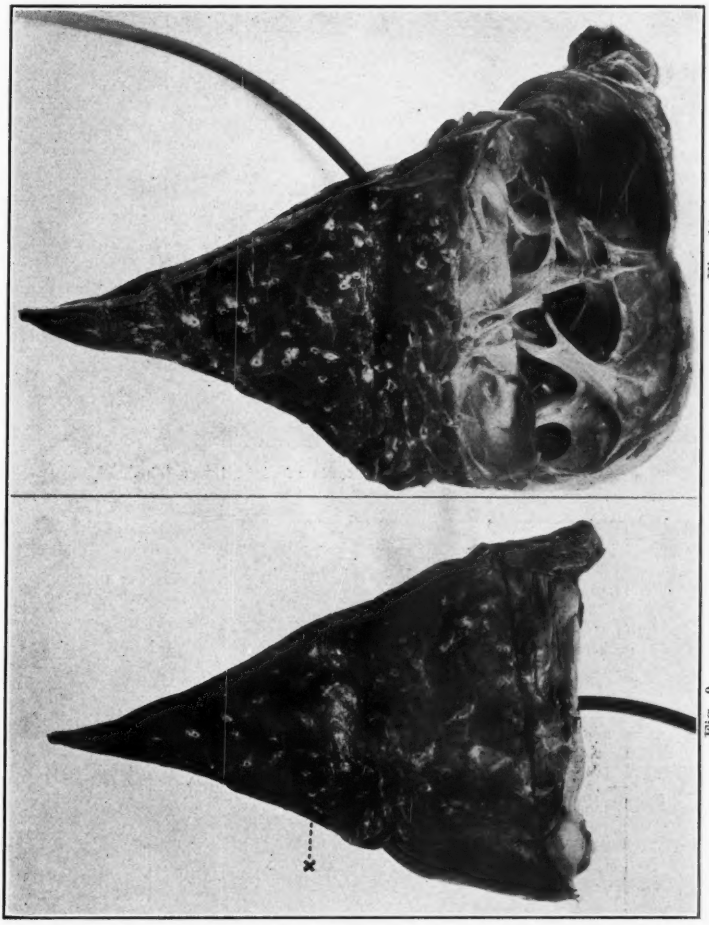


Fig. 9.—Mediastinal aspect of lower lobe. Small structure marked "x" is only bronchus entering lobe.

Fig. 10.—Lobe opened to demonstrate large multilocular cyst.

319435 (Fig. 11). The latter diagnosis was suggested by intimate family contacts, a positive tuberculin skin test, and a calcified tubercule in the left lower lobe. After the pathologic condition had been recognized as static over a period of several years, the lobe was removed (Fig. 12). No evidence of tuberculosis was found on microscopic examination.

Fig. 11.—X-ray film of multiple cysts of right lower lobe.

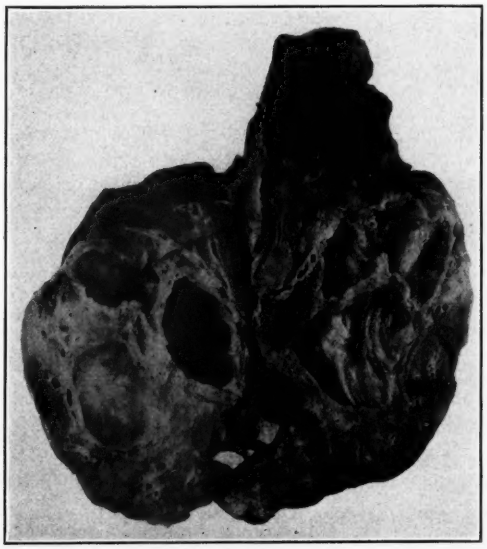


Fig. 12.—Lower lobe shown in Fig. 11.

A respiratory infection or operation on the upper respiratory passages may initiate symptoms referable to a previously silent pathologic condition in the lung. This occurs not infrequently with carcinoma of the lung and may also be seen in cystic malformations. Hemoptyses, cough and sputum in Case No. 336952 followed tonsillectomy at the age of four years. The boy was treated for nine years in a sanatorium under the diagnosis of lung abscess. At operation large cysts were found in both the middle and the lower lobes (Fig. 13). Despite the history the pathologic findings are interpreted as developmental malformations rather than chronic abscess cavities.

Fig. 13.—Right middle and lower lobes containing large cysts.

In two instances a thin-walled infected cyst presenting on the surface of the interlobar fissure has been deliberately opened at operation and a portion of its wall left adherent to the upper lobe. Only by this maneuver could the lobe be isolated without serious trauma to the adjacent lung tissue. Such a procedure requires completion of the resection as a one-stage operation.

TOTAL PNEUMONECTOMY

One-stage total pneumonectomy for bronchiectasis has been performed so rarely that a note concerning a successful case is not out of place.

Case No. 347793, a girl aged sixteen years, had been a semi-invalid for ten years because of weakness associated with a chronic cough. The sputum was foul and averaged 300 c.c. in twenty-four hours. During the year before admission there had been regular night sweats, and frequent vomiting associated with coughing spells.

X-ray examination showed opacity of the left lung field and displacement of the mediastinum toward that side. Films following lipiodol demonstrated bronchiectasis of both lobes of the left lung.

Fig. 14.—Left lung totally involved by bronchiectasis, atelectasis, and pneumonitis. One-stage total pneumonectomy with complete cure.

As the patient had been a resident of her town infirmary for six months and had apparently reached an optimum condition, the surgical program was undertaken after a period of seven weeks' observation.

Under avertin and gas oxygen anesthesia the sixth and seventh ribs were resected posteriorly. The pleural cavity was found completely obliterated by dense adhesions. The lung was mobilized by careful dissection. The dense inflammatory reaction and hypertrophied lymph nodes at the hilum made isolation of the major vessels and bronchi

impossible. The hilum was grasped by a tourniquet and the lung amputated. The stump was handled as in a lobectomy, by chromic catgut sutures. No mass ligatures were employed. The pleural cavity was drained with a catheter.

The operation took place on October 14, 1935. Inadequate drainage by the catheter made it necessary to insert a second one at a higher level on October 22. A bronchial fistula developed and a prolonged convalescence followed. On January 10, 1936, an upper thoracoplasty was performed to obliterate the empyema cavity. Sections were removed from ribs 1 to 5 inclusive. The empyema cavity rapidly healed and the bronchial fistula closed spontaneously. She is now in excellent condition with no cough or sputum and is rapidly gaining in weight. A photograph of the lung is reproduced in Fig. 14.

SUMMARY

A case mortality of 6.1 per cent is recorded in 49 patients in whom lobectomy or total pneumonectomy has been undertaken for bronchiectasis or cystic disease.

A mortality rate of 5 per cent is recorded in a series of 40 patients in whom lobectomy for bronchiectasis and cystic disease has been completed (including death following first stage operation).

A mortality rate of 2.6 per cent is recorded for 38 patients subjected to lobectomy by methods now recommended. The last 30 successive cases including one with the removal of the right middle lobe as well as the left lower have been completed without mortality.

Paralysis of the phrenic nerve as an independent procedure appeared to have little or no effect in 20 cases of basal bronchiectasis.

Two surgical programs are available: (1) one-stage lobectomy; (2) two-stage lobectomy. Each procedure has its indications, and choice should be made according to the problem presented by the individual patient. The total postoperative days in the hospital are approximately the same following the two operations.

If a two-stage lobectomy is chosen, a delayed second stage is strongly recommended. Symptomatic and physical improvement follows the first stage operation in a majority of instances, and the patient approaches the more hazardous step in an improved physical condition.

Three cases of postoperative hemorrhage are presented.

Three cases of cystic disease of the lung are briefly described and contrasted with an extreme instance of cystic bronchiectasis.

A case of one-stage total pneumonectomy for bronchiectasis is reported briefly.

BRONCHOSCOPIC ASPECTS OF BRONCHIAL TUMORS*†

With Special Reference to So-Called Bronchial Adenoma (Reports of Twelve Cases)

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DIAGNOSTIC BRONCHOSCOPY

IN A PAPER read before the Association two years ago,[1] we reported a series of cases of bronchial carcinoma in which bronchoscopic biopsy had confirmed the diagnosis. Attention was called to the fact that, though bronchoscopic biopsy would probably be positive in only about 75 per cent of the cases, the bronchoscopic findings, positive or negative, are *always* important.

As stated by Overholt,[2] bronchoscopy should inform the surgeon as to the presence or absence, and, if present, the location and extent, of a tumor in the accessible bronchi; the mobility or fixity of the tracheobronchial tree; and the histologic character of the lesion where biopsy is possible. Perhaps a little too much emphasis has been placed upon positive biopsy in the past. Certainly biopsy material, when obtainable, should be carefully studied, but we must not concentrate our attention so closely on biopsy as to neglect the other aspects of the bronchoscopic and clinical picture. If the accessible portions of the tracheobronchial tree are found entirely negative, so much the better; the surgeon knows that in such a case he can amputate any of the larger bronchi and not leave tumor tissue behind, though he must proceed with no knowledge of the histopathologic character of the lesion and rely solely on the clinical diagnosis.

Of course, when the first bronchoscopy reveals no endobronchial tissue for biopsy, or tissue removed for biopsy proves histologically negative, bronchoscopy should be repeated after a suitable interval, because very often either intrusion or *extension upward from the small branch bronchus in which the tumor originates* will have taken place, and biopsy will be possible. Exploratory thoracotomy should be done, and lobectomy or pneumonectomy considered, however, without waiting for positive biopsy, if a fairly certain clinical diagnosis of malignant tumor can be made.

*Read before the Nineteenth Annual Meeting of the American Association for Thoracic Surgery at Rochester, Minn., May 4, 5 and 6, 1936.

†From the Departments of Bronchoscopy and Pathology of the Temple University Hospital.

If a tumor is found in the accessible bronchi, a specimen of tissue should be removed for biopsy, but careful notation of the exact position and proximal extent of the lesion is almost equally important. In the case of malignant tumors, these findings will aid the surgeon in deciding between lobectomy and pneumonectomy and, in the more extensive lesions, between pneumonectomy and hopeless inoperability. We have seen several cases in which the x-ray examination, even with lipiodol, suggested a lesion involving only one lobe, with a normal main bronchus, and yet bronchoscopic inspection showed extension of the growth upward to the bifurcation of the trachea, making even pneumonectomy inadvisable.

According to Rabin and Neuhof,[4] only about 25 per cent of the bronchial carcinomas, those which are peripherally located, circumscribed, and generally inaccessible to bronchoscopic biopsy, are of good operative prognosis, while the remaining 75 per cent, less circumscribed, more centrally located, and accessible to biopsy, are most often inoperable. It is to be hoped that since the great improvements in the technic of pneumonectomy by Graham,[5] Overholt,[2] Rienhoff[6] and others, the prognosis of this latter group will improve. Incidentally, it is interesting to compare the views of Rabin and Neuhof[4] in regard to topography and prognosis with those of Tuttle and Womack.[7] Studies made by the latter workers lead them to conclude that "tumors of the major bronchi give symptoms earlier, extend more slowly, and are more amenable to surgical treatment"; while "tumors of the minor bronchi and the lung periphery cause fewer early symptoms and are more rapidly fatal." However this may be, as noted in one of our previous papers,[1] a number of successful lobectomies and pneumonectomies have been reported by Graham, Overholt, Churchill, and others, in which bronchoscopic biopsy was positive.

BRONCHIAL ADENOMA

Among the tumors of the larger bronchi, the majority are squamous-cell carcinomas, a number adenocarcinomas, and some carcinomas of "undeterminable" or "undifferentiated" types. Various benign tumors are also found, of which the most important and most interesting is the tumor most generally called "bronchial adenoma," or "adenomatous polyp" (Reisner,[8] Wessler and Rabin[9]). These tumors have also been called "carcinoids" (Kernam[17]), "benign glandular tumors" (Clerf and Crawford[3]) and simply "tumors" (Stout). Pathologists have great difficulty in recognizing these lesions and very often call them carcinomas. It is important to discover them early, because if not treated they gradully increase in size, producing bronchial obstruction and subsequently bronchiectasis, abscess, and empyema; it is especially important to differentiate them from adenocarcinoma because they require much less radical treatment.

Symptoms.—Hemoptysis is perhaps the most constant and conspicuous symptom, and for this reason many of the patients are sent to sanatoriums with a diagnosis of tuberculosis. Other common symptoms are those of bronchial obstruction, such as wheezing, productive cough, and dyspnea. On physical and roentgen examination, signs of obstructive emphysema, obstructive atelectasis, or empyema may be noted. On the other hand, most patients have very few symptoms or signs in the early stages.

Bronchoscopic Appearances and Biopsy.—As seen bronchoscopically, benign adenomas usually appear as smooth, rounded, reddish tumors in the larger bronchi, which jut out into the bronchial lumen and do not infiltrate the wall. Occasionally their surface is grayish in color and roughened. (Fig. 1.)

Biopsy is generally easy, but, as stated above, the histologic diagnosis is rather difficult and requires careful study.

Pathology.—(Frank W. Konzelmann.) Some of the cases in the series herein described have been called by competent pathologists carcinoma. One in particular, Case 6, concerning which there was considerable controversy, was studied at our request by a pathologist with an exceptionally broad experience in neoplastic disease. He was inclined to think that this case would "turn out to be a peculiar pulmonary cancer." We, ourselves, believed our earlier cases to be low-grade carcinomas. The publications of Geipel, Reisner, Wessler and Rabin, and others, and the very long clinical course of some cases (Cases 2 and 3) led us to question their malignant status. While the term "bronchial adenoma," so frequently applied, does not seem entirely acceptable because of the bizarre histology of these tumors, their nuclear structure and their apparent inability either to infiltrate or to metastasize indicate their relatively benign character. In a general way the twelve tumors described present comparable structure both gross and histologic. They all project into the lumen and seem not to be embedded deeply into the bronchial wall. None of our patients has died, so the true depth of penetration has not been determined by autopsy. The cases reported by Kramer,[18] in which autopsy had been done, showed some of the tumor mass extending between the cartilages. The surface generally has been covered by squamous epithelium, and a wide band of connective tissue lies between the surface covering and the tumor proper. The tumor cells generally have been collected in masses, sometimes without specific arrangement of the cells; more often the peripheral cells form a definite layer as is seen so characteristically in basal cell carcinomas of the skin. The more central cells are wont to lie loosely, unattached to one another. They are often cuboidal, sometimes flat, and sometimes columnar. Rarely a lumen is seen within the cell masses, and in at least two of our cases this lumen was filled with a mucoid material. In all, the nuclei have

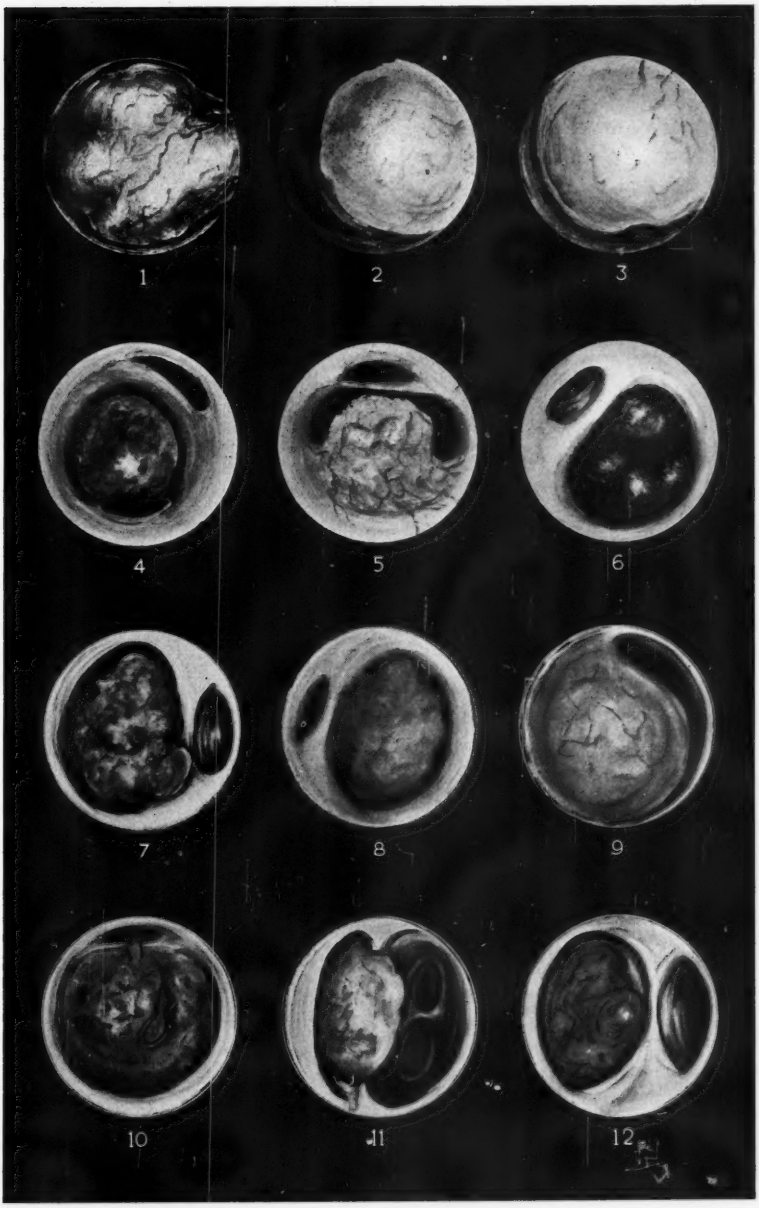

Fig. 1.—Bronchoscopic views of bronchial adenoma. These sketches represent the endoscopic appearances in the series of twelve cases herewith reported. (See case reports for description of each. The number under each view corresponds to the case number.)

the structure of normal, or nonneoplastic, cells. There is a delicate but definite nuclear membrane, a fine scattering of chromatin particles; nucleoli when present are small and stain deeply. Mitotic figures are exceedingly rare. The stroma varies. In some of the older tumors it has been quite dense and decidedly adult. In others it has been loose and rich in fibroblasts. In a few it has been mucoid. Some tumors have been rich in capillaries, and in these the close association of the capillaries with the epithelial cells has been striking. The thought that these tumors might be associated with nerve elements and be related to the carcinoids seen in the gastrointestinal tract has been considered. Some of the tumors have been impregnated with silver and fail to show the argentophile properties of carcinoids. Many believe that these tumors arise from the epithelium of mucous glands. We are not yet convinced of such an origin. We believe that they are benign tumors and that they may be treated as such if kept under observation, for it is not at all impossible that they may at some time undergo malignant transformation. (See case reports.)

BRONCHOSCOPIC TREATMENT

Bronchoscopic treatment of both benign and malignant bronchial tumors, by forceps removal, radon implantation, or electrocoagulation has been practiced by many bronchoscopists. According to Ellen J. Patterson's excellent review of the literature on benign bronchial neoplasms,[10] von Eicken[11] was the first to remove a benign bronchial tumor (enchondroma) by means of the bronchoscope. Shortly afterward Chevalier Jackson[12] reported his well-known case of "endothelioma" removed bronchoscopically. The pathologist regarded that tumor as malignant, but under the heading of "Remarks" Jackson stated that he did not advise attempting to remove *malignant* bronchial tumors with the bronchoscope, and that he had removed this one only because at that time he had thought it benign. He went on to say that the lesion was a "sharply circumscribed, non-ulcerated tumor of very slow growth" and that possibly it was "one of those tumors that is histologically malignant but clinically benign." Unfortunately we have been unable to locate the microscopic sections of this tumor, though Jackson is now of the opinion that it very probably was one of the tumors that are now being called "benign adenoma" of the bronchus. This case is therefore included in the series of cases of these tumors summarized herewith (Case 1).

We removed an "adenomatous polyp" with bronchoscopic forceps in 1932, and this case, though previously reported,[13] is also included, with follow-up notes. Two other cases reported at the same time as "benign tumors of inflammatory origin" are likewise summarized with follow-up notes and a discussion of pathology (Cases 4 and 5).

Deep x-ray therapy has proved disappointing in bronchial carcinoma, but Vinson and Leddy[14] reported encouraging results in 10 patients out of a series of 70. It is interesting to note that 7 of the 10 cases in which favorable results were obtained were histologically adenocarcinoma, though the great majority of bronchial carcinomas are squamous cell tumors. Is it possible that some of those that were improved may have been tumors of the type we are calling "adenoma"? We are including in the series of cases summarized herewith two cases previously reported by Chevalier Jackson[15] as carcinoma favorably influenced by roentgen therapy for a period of years (Cases 2 and 3). We recently reviewed these cases with Dr. Jackson and he wishes us to summarize them along with our group of so-called adenomas, because on study of the microscopic slides and the clinical records we find they fulfill histologically, as well as clinically, the requirements of this group.

Radon implantation and surgical diathermy have been advocated by Moersch and Bowing,[16] Kernan,[17] Kramer,[18] Morlock[19] and others in the treatment of tumors of the larger bronchi. All these measures have been used by us in treating the adenomas, and even some of the unquestioned carcinomas, with a view to maintaining the patency of the bronchial lumen and preventing suppurative complications resulting from bronchial obstruction, provided lobectomy or pneumonectomy was not to be done. In the benign cases, forceps removal and electrocoagulation of the base have proved curative.

CASE REPORTS

(Twelve Cases of "Bronchial Adenoma")

CASE 1.*—F., male aged thirty-five years, had had a "heavy cold" five years previously lasting a year, toward the end of which time he had spat up some blood. The symptoms were somewhat less severe in the summer than in the winter. At times a wheeze was noted and the patient described a sensation like that of a "ball valve" shutting off his breath at times. He spent two years in a sanatorium for tuberculosis, without having a positive sputum. Among the diagnoses made were "chronic right-sided bronchitis" and "right-sided asthma."

X-ray examination showed intermittent density of the right lower lobe, with elevation of the right diaphragm.

Bronchoscopy was done under local anesthesia (C. J.), and a large reddish tumor mass was found, filling a dilatation of the right stem bronchus. It appeared to spring from the right bronchial wall just above the orifice of the middle lobe bronchus. The tumor was removed piecemeal with bronchoscopic forceps. See Fig. 1 (1).

Course.—This patient is well today, about twenty years after removal of the tumor from the bronchus.

Histology.—Unfortunately the microscopic preparation had not been preserved, but the original report (by Ernest W. Willetts) described a growth that had in part the appearance of an endothelial neoplasm and some of the features of an epithelial neoplasm, with further comment that there was little nuclear change. All

*For previous report, see Ref. 12.

these points suggested at least the histologic structure found in the group of tumors herein described. Many were characterized by proliferating capillaries and the presence of tumor cells in close proximity to these capillaries, so that it was not an easy matter to distinguish neoplastic cells as being of epithelial origin. The comparatively normal structure of the nucleus was also noted. That this tumor was spoken of as being histologically malignant is not at all astonishing, for similar lesions have been repeatedly so called by other capable pathologists, and we ourselves were not at once convinced of their benign character.

CASE 2.*—M. H., female aged twenty-four years, complained of chronic productive cough with recurring severe hemorrhages and pain in lower right chest, onset four years previous to time first seen. For three years patient was thought to have tuberculosis, though sputum was always negative.

X-ray examination showed signs of bronchial obstruction at right base.

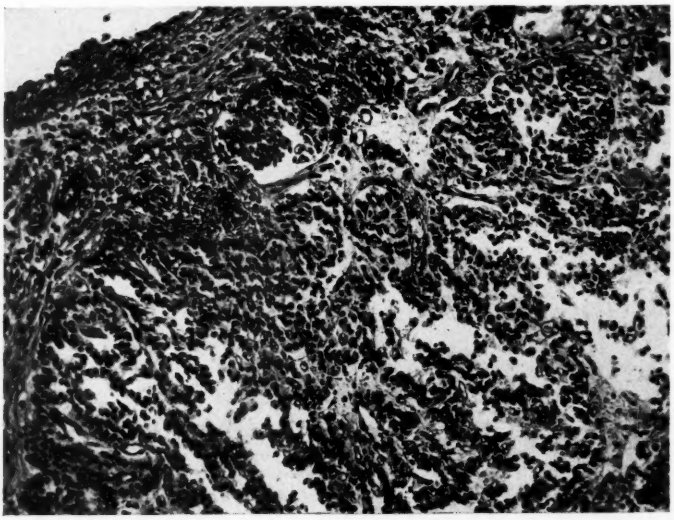

Fig. 2.—Note the nests of cells without regular arrangement. In the lower left-hand corner, a suggestion of adenoid structure may be seen. Cells generally are either cuboidal or low columnar but note also that in the larger nests they lie rather loosely, unattached to one another. (Case 2.)

Bronchoscopy (C. J.) showed rounded tumor mass obstructing right bronchus, which bled freely. Tissue removed with forceps and bismuth blown in for hemostasis. See Fig. 1 (2).

Course.—Treatment following bronchoscopic removal of endobronchial tumor consisted of transfusions because of secondary anemia, and deep roentgen therapy because of diagnosis of adenocarcinoma by the pathologist. This patient remains symptomatically well twelve years after treatment, or sixteen years after the onset of symptoms.

Histology.—(This tumor was originally diagnosed by Dr. B. L. Crawford as adenocarcinoma. After review of the case in the light of the subsequent clinical course, he believes it to be a "benign glandular tumor.")

*For previous report, see Ref. 15.

Microscopic study revealed many elongated and round spaces separated from one another by narrow strands of rather fine fibrillar connective tissue. The spaces were lined rather irregularly and partly filled by cells of varying size and shape. In some places these cells were columnar and bridged the space entirely where the space was small. The nuclei of these cells were oval. In other areas the space was distinctly adenoid. The cells occurred in one or two layers, rather irregularly placed, and in the center of the space there was a lumen. These cells were often intimately associated with blood vessels, which they sometimes surrounded, forming a papilla. Everywhere the nuclei were characteristic in their distinct but fine nuclear membrane, fine peppery chromatin granules and absence or inconspicuousness of nucleoli. (Fig. 2.)

CASE 3.*—B. S., female aged thirty-eight years, complained of nausea and vomiting, cough, weakness, and loss of weight. These symptoms were of three years' duration, dating from "pneumonia." Patient had had "several colds

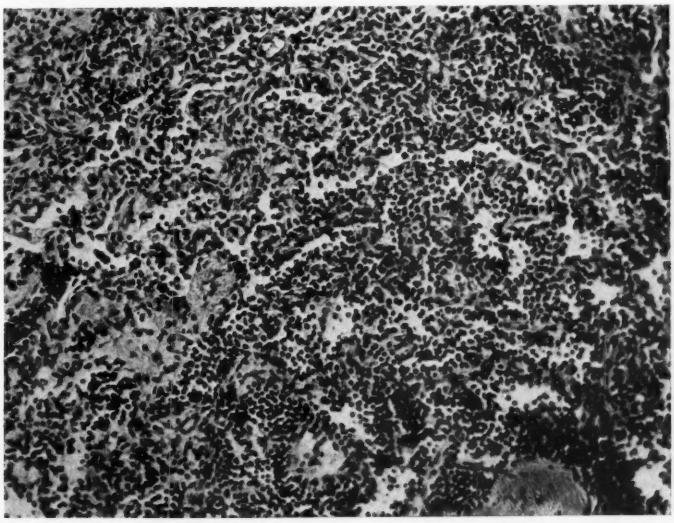

Fig. 3.—Note the nests of small cuboidal or polyhedral cells. An adenoid structure is hardly recognizable; yet, if the long flat spaces in the center of the photograph are carefully observed, it will be seen that the peripheral cells tend to line these spaces with a fair degree of accuracy. (Case 3.)

with fever and cough." She had had several attacks of hemoptysis, most of them during the menstrual period. The diagnosis based on physical signs was "lesion of left lower lobe and pleura, possibly thickened pleura with lung suppuration."

X-ray study was thought to show evidence of "effusion or empyema."

Bronchoscopy (C. J.) showed, just below the orifice of the left upper lobe bronchus, a nodule pinkish in color, covered with adherent exudate and completely occluding the left lower lobe bronchus. See Fig. 1 (3).

Course.—Deep roentgen therapy was given following bronchoscopic removal of the obstructing tissue from the bronchus, in view of the pathologists' diagnosis of carcinoma. A second bronchoscopy four years later showed some remaining "nodular masses of bleeding tissue" causing partial obstruction of the left lower

*For previous report, see Ref. 15.

lobe bronchus. Several bronchoscopic aspirations and another course of deep roentgen therapy were given at this time. Eight years later the patient was still living and enjoying reasonably good health. Her weight was 167 pounds.

Histology.—(As in the previous case, this tumor was originally diagnosed by Dr. B. L. Crawford as a carcinoma, but after review of the tissue in the light of subsequent developments he believed it to be a "benign glandular tumor.")

Microscopic examination revealed elongated spaces like the alveoli of a collapsed lung. These spaces in some parts were distinctly lined by a single row of deep staining cuboidal cells. In some areas the cells were more numerous and in addition to lining the space, loose unattached cells filled the lumen. Here again intimate relationship with blood vessels was a striking feature, and there was a tendency for shrinkage of tissue with pyknosis of nuclei. The supportive stroma was a little more adult and more dense than that of any of the other cases in our series. (Fig. 3.)

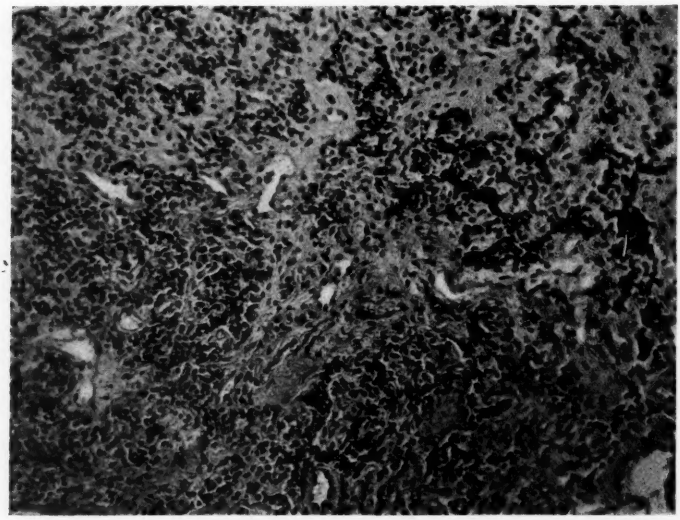

Fig. 4.—Note the nests of cells like those seen in the previous photographs. Cell nests are not so numerous but they are identical. Cells are not arranged with any great degree of regularity, although careful examination reveals an attempt to line the space. Shrinkage of the tissue may be noticed in the upper right where there is a greater degree of fibrosis, where the spaces are smaller and the cells shrunken and deeply stained. (Case 4.)

CASE 4.*—E. G., a girl fifteen years of age, complained of "loose cough" but little expectoration for five months, chills and fever, and loss of weight. The referring physician thought possibly a foreign body might be present in the right bronchus because of the presence of signs of bronchial obstruction.

X-ray examination had shown a "spot in the right lung"; though it was thought that, if there was any tuberculous lesion present, it was healed. Right lower lobe atelectasis.

Bronchoscopy (C. L. J.) showed a rounded reddish tumor mass in the stem bronchus, partially obstructing the middle lobe bronchus and almost completely obstructing the lower lobe bronchus. This tumor was removed piecemeal by bronchoscopic forceps. See Fig. 1 (4).

*For previous report, see Ref. 13.

Course.—Symptoms disappeared and the patient began to gain weight. Unfortunately she was obliged to move to another city, and bronchoscopy could not be done as frequently as before. She has, however, been practically symptom-free, except for one attack, for a period of six years. Recently she returned for comparative studies, and it was found that she still has a partially obstructed right lower lobe bronchus, but her general condition was very satisfactory.

Histology.—Microscopic examination revealed a surface covered by degenerated epithelium beneath which there were many irregular spaces. These spaces were filled with cuboidal cells possessing round or oval nuclei. Nucleoli were small or completely absent. Chromatin was in the form of fine granules. There was a distinct nuclear membrane. Mitotic figures were not seen. In many instances the cells lay so loose in the space that they appeared more like inflammatory elements, but frequently they lined the space, forming one or two distinct layers. It was rather striking that here and there a tiny capillary lay among the free cells. The

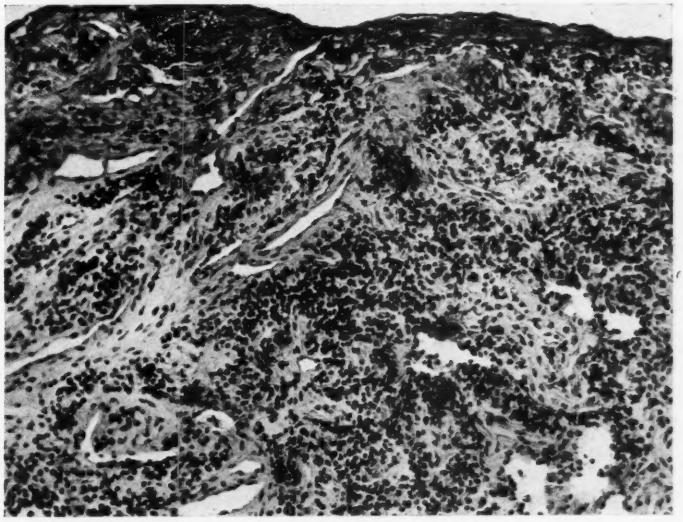

Fig. 5.—Compare the histology with previous photographs. It is much the same. Again, cells tend to be collected in spaces without any definite glandular arrangement except occasional evidences of lining layer. Here too the effect of shrinkage and fibrosis is in evidence with pyknosis of the neoplastic cells. (Case 5.)

supportive stroma was exceptionally rich in small engorged capillaries. In some of the tissue there were areas much like these, but there was a greater tendency for collapse of the tissue, the cells were shrunken, the nuclei stained rather deeply, nuclear markings were indistinct, and the cells that line the spaces appeared as flat cells. Originally this tissue was looked upon as herniated lung tissue rather than neoplasm. (Fig. 4.)

CASE 5.*—E. T., female aged twenty-five years, complained of hemoptysis and productive cough for about two years.

X-ray examination showed signs of obstructive atelectasis of right lower lobe.

Bronchoscopy (C. J. and C. L. J.) showed tumor obstructing lumen of right lower lobe bronchus. Tumor apparently sprang from the posterior wall just distal

*For previous report, see Ref. 13.

to the orifice of the first posterior branch. Treatment was by forceps removal and diathermy. See Fig. 1 (5).

Course.—Symptomatic cure at present time, five years after institution of treatment, but bronchoscopy still showed a sessile tumor mass in right lower lobe bronchus and lipiodol bronchography showed bronchiectasis of right lower lobe contrasting strikingly with normal bronchial tree of middle lobe. Despite bronchiectasis no productive cough was present.

Histology.—Microscopic study revealed many irregular spaces, somewhat elongated as one would expect to find in collapsed lung tissue. The supportive stroma between these spaces was not very much thicker than septums would be under these circumstances. The spaces were partly filled and incompletely lined by cuboidal and somewhat flattened cells. Some cells lay free in the lumen. They generally tended to be cuboidal and had round or oval nuclei, with fine peppery

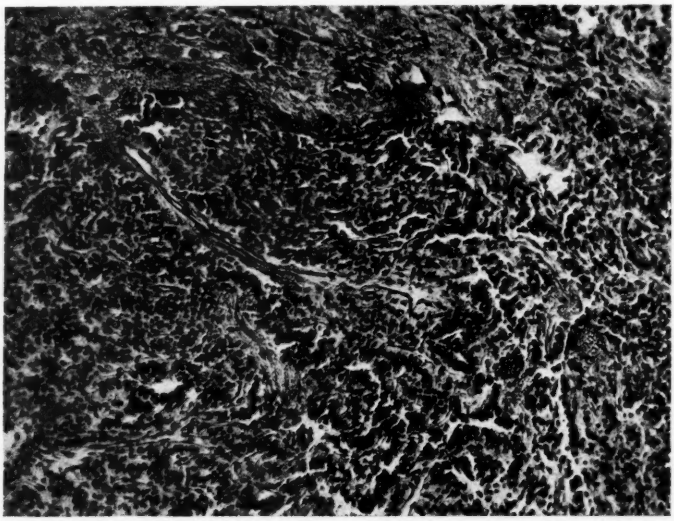

Fig. 6.—The adenoid structure is more accurately represented in this portion of this tumor. There were areas that resemble the previous pictures. Here rather definite lining cells are seen with few cellular elements lying loose in the lumen. There is a greater degree of fibrosis. Individually, the cells resemble those of previous cases. (Case 6.)

granules of chromatin, small nucleoli or none at all. In this case, there were areas in which the cells of the space were recognized only by dense strands of basophilic material (chromatin). (Fig. 5.)

CASE 6.*—A. R., a woman thirty-two years of age, complained of recurring pulmonary hemorrhages dating back two years prior to her coming to us. She stated that she had never regained her strength after "flu and pleurisy" three years previously. Since that illness she had been hospitalized several times, for a month or two at a time. She had been given six x-ray treatments. This patient had some hemoptysis, hemorrhages being especially noted at the time of the menses, the last one three weeks previous to admission. Several sputum analyses had been negative for tubercle bacilli.

*For previous report, see Ref. 13.

X-ray examination showed atelectasis of the left lower lobe.

Bronchoscopy, done in March, 1932, showed a multilobular reddish tumor in the left lower lobe bronchus. This tumor was removed piecemeal with the bronchoscopic forceps, after which a good view of what appeared to be a normal lower lobe bronchial tree was presented. See Fig. 1 (6).

Course.—Following removal of the tumor the patient had no more hemorrhages, gained about 10 pounds in one and one-half months. Follow-up records showed that she was symptomatically well four years after the removal of the bronchial tumor.

Histology.—Microscopic examination revealed cell masses with more or less perfect lumen formation. Many of the masses were solid and the peripheral cells arranged in an even column as if forming a basal layer. Sometimes they were suggestively columnar, more often cuboidal or polyhedral. The supportive stroma was of a loose, fibrillar texture. The surface of the nodule was covered by intact epithelium. There were three to four layers resembling squamous cells. A wide band of connective tissue separated this epithelium from the neoplasm. (Fig. 6.)

CASE 7.—A. A., woman thirty-eight years of age, complained of a dry cough for the past two and one-half years and dyspnea on the slightest exertion. She had sharp shooting pains in the chest and had expectorated blood on numerous occasions, the most recent just one week previously.

X-ray examination showed obstructive emphysema of the left lung.

Bronchoscopy (C. L. J.) showed a large mass of tumor tissue obstructing the left main bronchus, from which specimens were removed for biopsy. See Fig. 1 (7).

Course.—In view of the pathologist's opinion that this lesion was probably malignant, deep roentgen therapy was advised, and several courses were given. The patient showed little improvement and subsequent roentgen studies demonstrated the development of complete atelectasis of the left lung. She was requested to return for further bronchoscopic study and treatment, and a series of therapeutic bronchoscopies were done, at which sufficient tumor tissue was removed from the left bronchus to permit re-aeration. This patient is still under treatment, showing great symptomatic improvement, five years after the onset of symptoms.

Histology.—Microscopic study revealed huge masses of cells collected in the form of lobules. Between the lobules there was a fine fibrillar, sometimes mucoid, stroma. In some instances the lobules were small and consisted of what might be considered acini. The cells composing them were generally polyhedral and showed no regularity in arrangement. The lumen had the appearance of having been formed as the result of liquefaction of cells in the solid mass. In the larger masses many lumina occurred. In every instance the lumen was filled with mucus. Nuclei were again characteristic, with their fine peppery granules and inconspicuous nucleoli.

CASE 8.—E. M., female aged forty-five years, complained of productive cough for five years, sputum blood-stained at times. Other complaints were loss of weight and pain in the left side. There was a history of an appendectomy and some pelvic operation at about time of onset, from which patient dated illness. Symptoms were thought to be much worse following a cold two years previous to patient's first visit. The provisional diagnosis of "chronic bronchiectasis" had been made, but general medical treatment with postural drainage and the instillation of lipiodol had failed to bring improvement.

X-ray examination showed a "chronic suppurative process involving the left lower lobe, with atelectasis."

Bronchoscopy (C. L. J.) showed a pinkish tumor mass obstructing the left lower lobe bronchus. The point of attachment was apparently the left upper lobe

spur. Bronchoscopic removal with forceps was followed by the implantation of radon seeds and a course of deep roentgen therapy, in view of the pathologists' suspicion of malignancy. See Fig. 1 (8).

Course.—Two months after institution of bronchoscopic treatment, patient had gained 30 pounds in weight and symptoms had practically disappeared. One year later she returned for comparative studies, and conditions, both general and local, were found very satisfactory. A small amount of tissue was again removed from the left lower lobe bronchial orifice, but obstruction at this time was very slight.

Histology.—Microscopic examination of the nodule in this case revealed a perfectly intact surface epithelium of the squamous cell variety. A dense band of connective tissue separated the epithelium from the neoplasm, which might be said

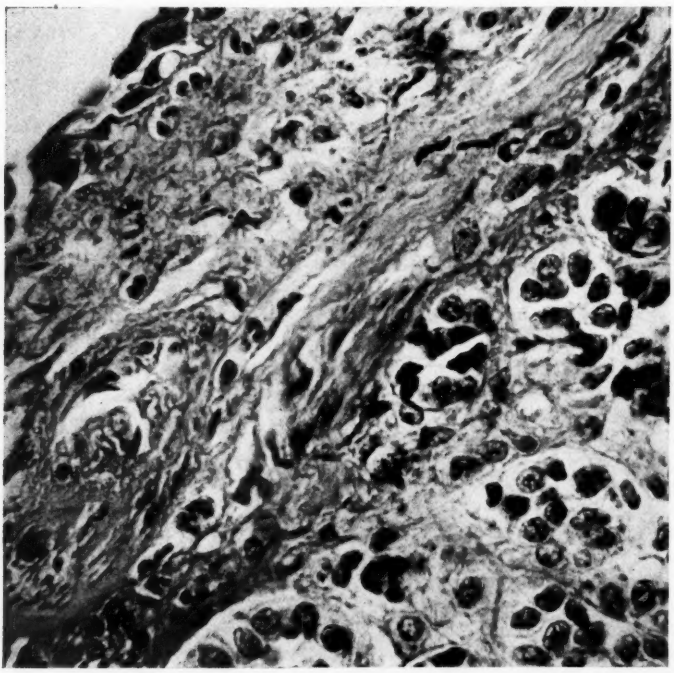

Fig. 7.—A higher power photograph to demonstrate the cellular detail. Note in the upper left the intact epithelium, and beneath it the dense band of connective tissue, which is rather characteristic of parts of these tumors. Note the rather distinct acini. The cells are not definitely lining cells but lie more or less loose within the lumen. They are of irregular shape but fairly uniform in size. The nuclei reveal very delicate nuclear membranes with small inconspicuous nucleoli. Some nuclei possess no nucleoli. Observe also the fine granules of chromatin. There are no mitotic figures in this tumor. (Case 8.)

to be circumscribed but certainly not encapsulated. There were irregularly shaped spaces that were either long and narrow, or oval, filled with cells. In some places the cells tended to be cuboidal and to line the space with rather striking regularity. In other areas they were scattered within the space as if without any purpose. It was striking to see columnar elements extending the entire width of the space. Free cells also occurred without any evidence of cohesion. Nuclei were rather characteristic, with very delicate membranes, scattered particles of chromatin, small or completely absent nucleoli. (Fig. 7.)

CASE 9.—A. H., female fifty-six years of age, complained of productive cough for one and one-half years, with hemoptysis developing a few months after the onset. She was sent to a sanatorium, having had a diagnosis of pulmonary tuberculosis made at a well-known clinic. The physicians at the sanatorium suspected a bronchial tumor because of obstructive emphysema, and therefore advised bronchoscopy.

X-ray examination showed, at different times, obstructive emphysema, obstructive atelectasis, and pleural effusion.

Bronchoscopy showed a "polyp in the right bronchus," of which a portion was removed for biopsy, tissue being sent to a number of pathologists for opinion. See Fig. 1 (9).

Course.—In addition to bronchoscopic treatment by means of forceps removal, radon implantation and electrocoagulation, a considerable amount of deep roentgen therapy was given.

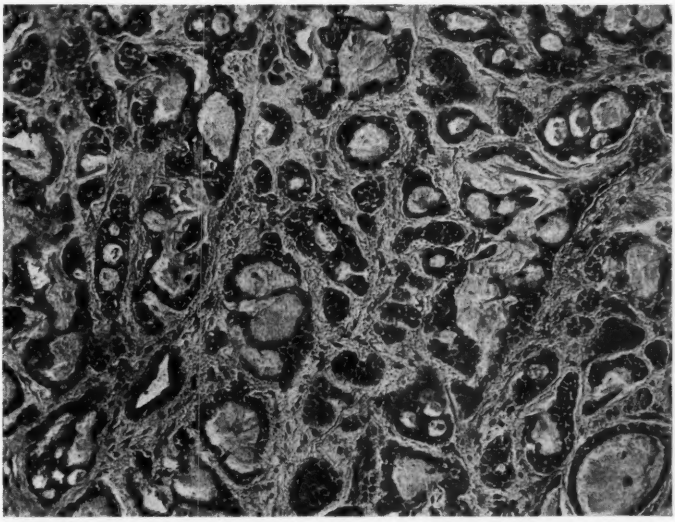

Fig. 8.—At first glance the histology of this tumor is unlike that of any of the others. Nearly every cell nest possesses a large space filled with mucus. The accumulated mucus seems to have compressed the tumor cells about it. They are uniform in size although they vary in shape. About the mucus they have a definite lining arrangement, but in the solid masses of cells the arrangement is most irregular. The intervening stroma in some parts of this tumor is itself mucoid. (Case 9.)

On this patient's first visit to our clinic, only a diagnostic examination was made, all the treatment during the interval being given by a bronchoscopist in her home city. At the time of her second visit, almost two years later, she had not had any treatment for about six months, and she was suffering marked dyspnea as a result of bilateral bronchial obstruction. Large masses of tumor tissue were removed by means of forceps and electrocoagulation. A good palliative result has now been obtained in this case by relief of bronchial obstruction, but the ultimate outcome is doubtful.

Histology.—The surface was covered by intact pseudostratified, ciliated epithelium. The neoplasm proper was circumscribed but not encapsulated. It consisted of irregular masses of polyhedral cells separated from one another by a fine

fibrillar, and in some places mucoid, stroma. Many of the cell masses were solid. Some possessed a lumen filled with mucoid material. The cells were not regularly arranged. Columnar or cuboidal elements at the periphery of the mass in many areas were flattened elements in more or less concentric layers. The cell nests were often bizarre U-shaped or J-shaped areas. Again the nuclei were characteristic, with their fine granules and inconspicuous nucleoli. (Fig. 8.)

CASE 10.—J. C., female twenty-eight years of age, complained of productive cough intermittently for two years, dating from three attacks of "pneumonia" occurring within one month. The sputum was blood-streaked but not odorous. Pain in the right chest was another symptom. The patient had been under observation for three months in a hospital in Boston, during which time she had had a course of injections of vaccine made from sputum.

X-ray examination showed a density in the region of the right lower lobe with some atelectasis.

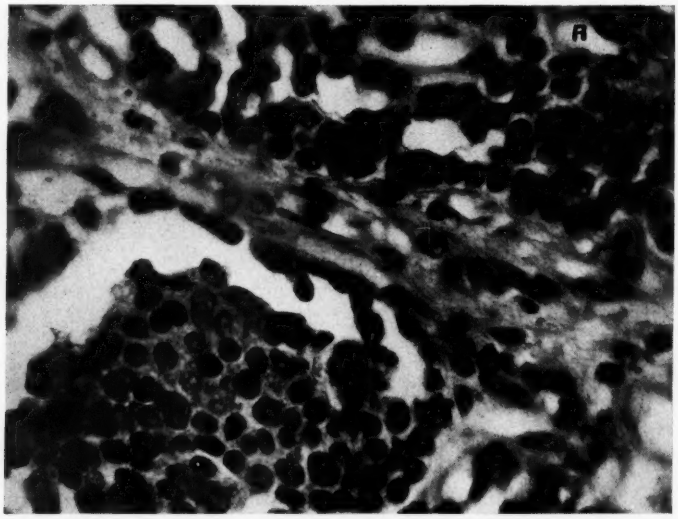

Fig. 9.—Higher power photograph to show cellular and nuclear detail. That some of the cells tend to line the space is in evidence; some form solid masses, others lie more or less loosely. At *A* a small capillary may be seen among the tumor cells. Note the nuclear structure and compare with Fig. 7. (Case 10.)

Bronchoscopy (C. L. J.) in August, 1935, showed a profuse amount of bleeding tissue obstructing the right bronchus. Large masses of tissue were removed with bronchoscopic forceps and blood-stained secretions aspirated. See Fig. 1 (10).

Course.—Further bronchoscopic treatment was advised and surgical consultation suggested. The patient came under the care of a thoracic surgeon, who did another bronchoscopy and removed additional tissue. When last heard of she was still under bronchoscopic treatment with favorable progress.

Histology.—This neoplasm differed slightly from others described in this series. The cell masses encountered were larger and more widely separated, except for some areas in which apparent collapse had occurred, with the formation of long strands of basophilic material (chromatin) lying within narrow spaces. In the former area there was a distinct tendency for one or two layers of peripheral cells to line the space, while more central cells showed less cohesion to one another. It was

most striking in this case that tiny capillaries were found among the free cells. Sometimes the cells were arranged very distinctly about a thick-walled arteriole. The stroma was of a moderately dense texture and quite rich in capillaries.

CASE 11.—A. L., female thirty-three years of age, complained of productive cough for two years, dating the onset of her symptoms from "pneumonia." She had spent the nine months previous to her first visit at a sanatorium for pulmonary tuberculosis. At the sanatorium she had had many negative sputum examinations. She complained of afternoon elevation of temperature, chills and night sweats, but she had gained weight (22 pounds in nine months). (Fig. 9.)

X-ray examination showed a lesion of the left upper lobe, with some atelectasis.

Bronchoscopy (N. M. L. and C. L. J.) showed a tumor mass projecting from the left upper lobe bronchus, which was removed piecemeal by bronchoscopic forceps. See Fig. 1 (11).

Fig. 10.—The structure here compares favorably with Cases 2, 3 and 4. Note the uniformity in cell size; the suggested but not typical adenoid arrangement. Observe also areas of fibrosis and pyknosis of tumor cells. (Case 11.)

Course.—This patient has gradually improved symptomatically, and comparative roentgen and physical examination shows clearing of the left upper lobe lesion. She returns for bronchoscopy at intervals but there has been no tissue visible in the orifice of the left upper lobe bronchus for several months.

Histology.—Microscopic examination revealed elongated spaces filled and incompletely lined by cuboidal elements. Some of these cells lay wholly unattached within the space. The nuclei were characteristic in their fine chromatin granules and inconspicuous nucleoli. The supportive stroma was of fine fibrillar structure and was moderately rich in blood cells. (Fig. 10.)

CASE 12.—L. G., female aged forty-two years, complained of an "irritated feeling" in the chest, for the past year, with a dry hacking cough and wheezing. She had lost 30 pounds in weight. She stated that she had always been in good

health except for "sinus trouble." She had had a polyp removed from the nose nine years previously. The diagnosis of asthma had been made at one time, but all medication failed to remove the wheeze.

X-ray study was reported "juvenile tuberculosis plus recent tuberculosis of left lung."

Bronchoscopy (C. L. J.) showed masses of polypoid tissue obstructing the left bronchus, and this tissue was removed with bronchoscopic forceps. See Fig. 1 (12).

Course.—After bronchoscopic removal of most of the obstructive tissue this patient was given a course of deep roentgen therapy. She is still under observation, but the bronchial stenosis has been relieved and she is symptomatically well except for occasional pains in the chest.

Histology.—Microscopic study revealed a dense adult stroma. The neoplastic cells were arranged more typically than in any of the other cases. In many acini there were distinct basal generative cells, and upon these were placed cuboidal or columnar elements with basally placed nuclei. There was a tendency for free, unattached cells to lie within the lumen. The cytoplasm of all cells was filled with a granular material (mucus).

CONCLUSIONS

1. Benign as well as malignant endobronchial tumors occur, and the bronchoscopic aspects aid greatly in distinguishing the two.

2. Diagnostic bronchoscopy is of value, *whether or not* the tumor is visualized in the accessible bronchi and specimens are taken for biopsy, because it may show indirect evidence of neoplasm; *if entirely negative*, it will demonstrate the *normality* of the larger bronchi, thus indicating the feasibility of surgical extirpation.

3. One of the most important groups of bronchial tumors is that constituted by the so-called "benign adenomas," which are coming to be recognized as a clinical and pathologic entity.

4. The histology of the so-called benign adenomas is confusing to those pathologists unfamiliar with this type of tumor; for, while the cellular pattern is fairly uniform and constant, it is not comparable with that seen in benign glandular tumors elsewhere.

5. Bronchoscopic treatment, by forceps, electrocoagulation, radon or radium, is especially effective in the case of benign tumors, but it is of at least palliative value in the malignant ones.

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DISCUSSION OF SYMPOSIUM ON SURGERY OF THE LUNGS AND MEDIASTINUM: "AN EXPERIMENTAL STUDY OF SOME OF THE PHYSIOLOGIC CHANGES FOLLOWING TOTAL PNEUMONECTOMY" BY LONGACRE, CARTER, AND QUILL; "RESULTS OF FIFTEEN CONSECUTIVE ONE-STAGE LOBECTOMIES FOR BRONCHIECTASIS" BY O'BRIEN; "LOBECTOMY AND PNEUMONECTOMY IN BRONCHIECTASIS AND CYSTIC DISEASE" BY CHURCHILL; "INTRATHORACIC ANATOMICAL READJUSTMENTS FOLLOWING COMPLETE ABLATION OF ONE LUNG" BY RIENHOFF, JR.; AND "BRONCHOSCOPIC ASPECTS OF BRONCHIAL TUMORS, WITH SPECIAL REFERENCE TO SO-CALLED BRONCHIAL ADENOMA" BY JACKSON AND KONZELMANN.

DR. EVARTS A. GRAHAM.—There are a number of points that I wish to speak of, and I shall therefore be obliged to skip over complimentary remarks which I should like to make about the excellent results reported by Dr. O'Brien, Dr. Churchill and Dr. Rienhoff, and various other matters.

I think it is particularly timely that Dr. Jackson has reported on the question of the confusion which exists in the literature because of alleged cures of bronchiogenic carcinoma, by all sorts of methods which are not very likely to cure such patients, and has called attention to the fact that many of these alleged cures of carcinomas have really been cases of benign tumors. The frequency of benign tumors of the bronchi I am sure is not properly appreciated, and I think we are greatly indebted to Dr. Jackson, himself a bronchoscopist, for emphasizing this particular point.

The main part of my discussion, however, I should like to direct toward Dr. Rienhoff's paper. For some time I felt that Dr. Rienhoff must be wrong in his conclusion that it would be possible in the majority of cases, or even in a consider-

able number of cases, of total pneumonectomy, to obtain a successful result without paying any attention whatever to the exudate which accumulates in this large space after the total removal of the lung. It was for that reason that in the first case of mine to which he alluded I felt it was necessary to perform a thoracoplasty in order to obliterate the large space. I feel now, however, after convincing demonstrations on the part of Dr. Rienhoff, as well as after some convincing experiences of my own, that I was wrong and that he was right. I am not quite willing to say that I was a hundred per cent wrong. I think it is too early to say that thoracoplasty will never be necessary in these cases. I do, however, feel that thoracoplasty is probably not a necessary procedure at the time of or even soon after the total removal of the lung; although even on this point we may change our minds later in order to minimize the effects of an empyema which sometimes occurs.

The title of Dr. Churchill's paper dealt with congenital cystic disease of the lung, but I suppose for lack of time he did not have the opportunity to tell us specifically anything about his results with that condition, and it is for that reason and also because of my desire to compliment Dr. Rienhoff for encouraging us to hope for an organization of exudate in the pleural cavity, that I should like to show a few slides. This patient was first seen by Dr. D. M. Carr of Memphis, but for some reason fell into my hands. She is a little girl, five years old, and from early infancy she has had a cough and sputum. There were times, however, when she was completely free from all symptoms of cough and expectoration. This happens to be a film that Dr. Carr made himself. Our films were quite similar, made last fall. On the lipiodol film you can see the dilatations of bronchi, involving the entire lung. Total pneumonectomy of the left lung was carried out about the middle of February, and this is a picture of the lung cut through, after its removal. The lower lobe of this lung presents a typical picture of bronchiectasis. I should like to call attention, however, to the fact that the upper lobe contains numerous small cystlike structures which do not have a thick wall. The question is therefore brought up, as to whether or not we were perhaps dealing with a congenital cystic disease of the lung which happened to become infected, or a more or less ordinary variety of bronchiectasis. This particular case, as well as one I am going to show in a moment, I think has a very interesting bearing on our conceptions of the possibility of congenital bronchiectasis. The patient made a complete and satisfactory recovery. Here is the x-ray film, slightly more than two months after the operation. This is in entire agreement with everything Dr. Rienhoff said this afternoon. There was no drainage in this case; nothing was done to the fluid which was allowed to accumulate in the chest; the patient was not even aspirated a single time; the trachea is still in the midline, indicating that perhaps the lung has not pushed over very much. At any rate, the youngster is perfectly well. Whether or not the pleural cavity is filled with the exudate like Swiss cheese which he showed, or what it is that is filling it, she is perfectly well; she is spending the time at her mother's request at the Children's Convalescent Farm, fifteen miles from St. Louis, running and playing and leading an active life.*

Strangely enough, at the same time, within three days after the first little girl arrived in the hospital, another little girl, this one seven years old, presented herself with a similar condition, again in the left lung. In this case, however, there is a history of the aspiration of a peanut three years before, which was removed by bronchoscopy by Dr. Arbuckle several weeks after its aspiration. This youngster was more or less completely incapacitated because of frequent recurrences of infection of the lung and the usual course of events that one sees in ordinary severe

*On January 4, 1937, I received a letter from the mother from Florida, where the family now lives, stating that the child has remained perfectly well.

bronchiectasis. A total removal of the lung was carried out. When it was cut open later, it was found that there was generalized bronchiectasis. The child was treated without drainage and made an uneventful recovery except that on the second postoperative day she developed a stenosis at the site of a tracheotomy scar, which resulted from a tracheotomy three years previously following the bronchoscopic removal of the peanut. The second stenosis necessitated another tracheotomy. Aside from that complication, however, she made an uneventful recovery.*

These two cases will be reported in more detail later. In some cases infection will doubtless occur which will necessitate drainage. These two examples, however, show that at least in some no drainage is necessary. I should like at this point to call attention to certain points about the operative approach. In female children I believe that it is much better, for cosmetic reasons, to make an anterior incision below rather than above the mammary gland. Not only does the immediate result give a more pleasing appearance, but later, after the gland has undergone mature development, the scar will be more or less completely concealed. The lower incision is, of course, not so directly over the hilus as the upper one. This apparent disadvantage, however, is of no consequence if one divides as many costal cartilages as are necessary for proper exposure. Again, there is much advantage in dividing the cartilages rather than the bony parts of the ribs because the former can be readily sewn together again with catgut by simply passing through the ends a cutting needle containing the suture, and the necessity of drilling holes through the bone is thereby avoided. Moreover, even if the cartilages do not heal in exact anatomic alignment, the defect cannot be made cut in an x-ray film, as it can if the bony parts of the ribs have been cut through. In other words, after a few years, when the mammary gland has developed sufficiently to conceal the scar, it will be impossible to detect even by x-ray examination that the patient has had an intrathoracic operation.

DR. JEROME R. HEAD.—Certain problems concerning the compensatory changes which take place following lobectomy and pneumonectomy have interested me very much. It is possible that the points which I wish to bring up explain the findings in the cases which Dr. Graham has just presented. In these there were two distinct types of bronchiectasis in the same lung: thick-walled cylindrical dilatations in a sclerosed and atelectatic lower lobe and thin-walled saccular enlargements in the lung above and adjacent.

The first animal experiments on bronchial obstruction were reported by Raynaud in 1837. He found that when a lobar bronchus was obstructed the lung distal to the obstruction became atelectatic and shrunken and the distal bronchi collapsed and cordlike. He also noted that the lung adjacent to the atelectatic lobe became emphysematous and, what is of particular importance, that its bronchi became dilated. These experiments were repeated by Lichtheim in 1867, who observed further that this adjacent pulmonary dilatation was occasionally so extreme that the lung ruptured.

In clinical lipiodol studies of cases of bronchial obstruction one observes this adjacent bronchiectasis. I have seen it in cases of foreign body and bronchiogenic carcinoma. In cases of atelectatic bronchiectasis one always finds a different type of dilatation in the lobe above that chiefly affected and in the mediastinal portions of the opposite lung. It has always been my belief that these adjacent bronchiectases were caused by the atelectasis. It seems quite possible that this is the explanation of the cases shown by Dr. Graham.

If atelectasis of a lobe will produce traction bronchiectasis in the adjacent lung which dilates to fill the defect, one would expect that removal of a lobe or a lung

*She has been seen frequently since that meeting. She attends school regularly and is perfectly well.

would produce the same pathologic condition. That Dr. Carter and Dr. Longacre and Dr. Rienhoff have failed to find it, probably means that the observations of Raynaud and Lichtheim were incorrect and that some other explanation will have to be found for these adjacent dilatations in cases of atelectasis. The point is one of considerable importance and should, I believe, be carefully considered. It is quite possible that in some cases the removal of a bronchiectatic lobe produces bronchiectasis in the lobes remaining.

DR. HOWARD LILIENTHAL.—I listened with much profit and pleasure to these interesting contributions.

In Dr. O'Brien's paper I noted the way that he treated the stump. As you perhaps know, those of you who have read the back literature, the first lobectomies that were reported for suppurative disease were fatal because the chest was closed and the bronchus later opened with following tense suppurative pneumothorax. It was in 1914 that I did the first operation with drainage of the chest, and the patient recovered. That was twenty-two years ago, and I have a very fine, symmetrical, good-looking young man, in the drug business now, to show for it. The next three patients also recovered. I fancy that this encouraged me too much, because after that my mortality rate was between 30 and 40 per cent. Fortunately, this proportion is now far less. I do not regret one single case in which there was a fatality, because the patients had waited too long and were in desperate straits. Of course one does not want to be an executioner, but I do not feel so badly about it as I would if time had not almost proved that I was right in deciding to operate.

Relative to the ligation that Dr. O'Brien performed, I used to secure the stump in this way, in my early cases, most of them being in children. But the right way, I say with all due respect to Dr. O'Brien with his beautiful results, is to employ the Shenstone or a similar tourniquet, put on the ligature, through the stump so it cannot slip off when atrophy occurs in a few days; I tighten it, take off the snare, and then I pick up each vessel separately and tie it separately, because the stump atrophies so rapidly that the arteries may become pervious and there may be dangerous hemorrhage.

I have made up my mind not to operate in almost any case of bronchiectasis until the method of Dr. Maurice Berck of New York has proved a failure. I spoke about this at the Association's last meeting, and I intend to speak about it until I hear people get up and say that they have tried it before doing the still dangerous lobectomy. When you can by x-ray treatment, even in a few weeks, reduce the sputum from a pint to an ounce and a half a day, it is well worth considering.

Dr. Churchill's figures were perfectly astounding and thrilling. There is one point to be mentioned which has nothing to do with thoracic operative or technical surgery. It was brought to my mind by these figures. Dr. Churchill counted one death in a two-stage operation before the second stage was performed. I maintain that that is not fair. He should not count this as a death from lobectomy.

I want to ask Dr. Rienhoff whether there was drainage in the one case in which there was a pericarditis and the patient died. If I suspect that there is a pericarditis of a septic nature, I always advise drainage.

I did a total pneumonectomy in 1917, and the man is still alive and working. The wound through drainage was permitted to close without plastic operation. I presented the patient at the Atlantic City meeting of this society, and some of you may remember him. It is fair to say that this man now has a bronchial fistula, open, although he is working and well. I did not report this case as a total pneumonectomy because the late x-ray picture revealed lung tissue in the upper part of the right side of the chest, which I now know was lung pushed over from the left. Physical signs may be present in the side from which an entire lung has been removed.

Dr. Jackson's paper was very interesting to me. I had one of those cases myself, and it taught me a valuable lesson. An expert pathologist, about nine years ago, the late Dr. Yankauer, examined the patient and found a tumor which he believed to be malignant; and after all kinds of trouble, during which the patient almost died, he managed to remove a specimen. The piece was examined and was pronounced a carcinoma of some kind—I do not remember what kind. But I do know that the patient is alive and well now, sends me a box of cookies every Christmas, and not long ago I had the specimen examined again and I was informed that pathologists' views had changed. So had mine. The tumor was probably one of these that Dr. Jackson has described today.

As to the method of allowing the fluid to remain in the chest postoperatively, it is a beautiful thing when it works, and I see no reason that it should not, except that in the suppurative cases there is still danger that something may happen, a bronchus may open, with tense pneumothorax and death before we can reach the patient. Suction drainage appears safer to me than firm closure of the chest after pneumonectomy.

DR. RICHARD H. OVERHOLT.—I should like to show four lantern slides to illustrate one or two points in lobectomy technic. I agree with Dr. Churchill's principle of adjusting the one- or two-stage operation to the particular situation found at the time of operation. I think Dr. Churchill should receive a great deal of credit for emphasizing the delay between the first and the second stage procedures, and also for his flexibility of adaptation of the one- and two-stage procedures.

(Slide) I have carried out lobectomies in fifteen patients; two were for carcinoma and two for lung abscess. In the cases of carcinoma and lung abscess, it was necessary, of course, to do a one-stage procedure. In the eleven bronchiectasis patients we chose to do the two-stage operation in three instances, and the prediction of Dr. Churchill that the hospital stay would not be longer for the two operations than for a one-stage operation was borne out in these cases. I was interested to follow these patients and find that six are perfectly well, but four still have some residual cough and expectoration.

(Slide) I have had an opportunity in the past year to consider lobectomy in bilateral disease in two instances. In one patient we have finished a resection of three of the five lobes. In this patient, aged nineteen years, symptoms were present for sixteen years. There was suppurative bronchiectasis present for fourteen years, and hemoptysis was present repeatedly for one year. Note the shadow indicating the bilateral involvement, with marked emphysema of the upper lobe on both sides.

(Slide) We resected the right, middle and lower lobes in June, 1935, and did a two-stage lobectomy. It was interesting to follow the course of the patient as far as the amount of expectoration was concerned, with each stage of these various operations. At the first operation, the patient was raising approximately four boxes a day. After the first stage lobectomy on the right side, the sputum was reduced to three boxes, and, after the second, to two boxes. After the first stage lobectomy on the left side, the sputum was reduced still further, and after the fourth and final operation the sputum had been reduced to about a tablespoonful a day. A lipiodol injection of the tracheobronchial tree recently showed the stumps of the lower bronchi on both sides, which explains this residual cough. Now two months following this operation, the patient is so delighted to be free of this tremendous coughing and raising that she is perfectly satisfied with this very slight residual symptom.

We have started a lobectomy on a second patient, with bilateral bronchiectasis. Neither lower lobe is atelectatic at this time. We feel that the application of the two-stage operation on each side is very important in order to let the upper lobe expand and adjust itself, before the final removal of the lower lobe.

DR. JOHN V. BOHRER.—The text of my remarks will be a commentary on the paper read by Dr. Jackson. He showed a case in which there was a bronchiectasis after he had removed a bronchial tumor, and remarked that the lobectomist would have to wait, since this bronchiectasis was entirely dry. The fact that a patient with bronchiectasis does not expectorate is no proof that the patient is not suffering from the presence of the disease.

I should like to give a short report of a case that came to my attention. A little girl six years of age had a huge lung abscess, which we drained. At the time of drainage it was known she had a bronchiectasis of that same lobe. It was interesting to speculate what would become of the bronchiectasis following the drainage. We discharged the child, after the bronchial fistula closed, apparently well. She remained at home for four years but was seen occasionally in the Follow-Up Clinic. The mother reported that she had no expectoration whatsoever, and we were quite satisfied.

At the end of the fourth year she came to the clinic, where it was observed that she had not done well, had not grown, and was undernourished. With the mother's permission the child was readmitted to the hospital for observation. She was put to bed at once and observed for a period of six weeks. At no time during this period did she have a normal temperature, its range being between 100° and 101°. During the four years she had remained at home she had been going to school, doing the ordinary stunts that a child does, and evidently running a fever.

After due consideration we subjected her to a lobectomy, in spite of the fact that at no time during her stay in the hospital, even with postural drainage, did she have any expectoration.

Since then the child has developed in a perfectly normal way and has shown very much better development than she had in the years prior to the operation.

DR. J. J. LONGACRE.—The problem as we have attempted to outline it here is an attempt to evaluate to what extent an animal will adapt itself to the total removal of one lung. In short, following the removal of about 50 per cent of the functional surface area of the lung, to what extent will an animal be limited in its activities. We also have attempted to find out just how quickly this comes about.

These experiments have shown thus far that, whereas at rest these animals have shown no embarrassment whatsoever, after pneumonectomy as we increase the amount of strain that we put on them they show more and more embarrassment. Over a period of time that amount of embarrassment tends to decrease, though over the period that we have followed them we find that they do not approach entirely or completely their preoperative levels.

Closely parallel to this degree of distress we notice that there is a degree of unsaturation of the arterial blood. Clinically, we feel that with this test, i.e., finding the degree of unsaturation of the arterial blood in response to a certain amount of strain on the patient (for example, either having him travel over a certain number of steps or else in a form of bicycle somewhat similar to a treadmill), it may be possible to evaluate more completely and accurately the cardiorespiratory reserve of that patient before submitting him to a thoracic operation.

The enlargement of the remaining lung following pneumonectomy has long been known. The question of compensatory change is still, however, unsettled. Laennec in 1819 was the first one to speak of pulmonary hypertrophy. Celice in 1929 again raised the question. Hilber, in 1934, in Germany, reported that in rats, following the removal of one lobe, there was not only a compensatory emphysema of the remaining lobe but also actual new generation of lung tissue, with new atria, new alveoli, and even new blood vessels, entering that area.

The importance of the answer to this question is reemphasized by the findings in our anoxemia test, which indicate that immediately following pneumonectomy the

cardiorespiratory reserve is cut in half, whereas over a period of time this tends gradually to return toward normal. As far as we have carried the work we have found that they still come only within 50 per cent of their preoperative levels.

For this reason we are eager to continue further and to find out whether this phenomenon, as we find it, that is the enlargement of the lung, in spite of the still existing decrease in cardiorespiratory reserve, does not lie in the anatomic changes within the lung itself; and I feel that the work of Rienhoff is showing us the way, whether it is a hyperplasia or a compensatory emphysema. Further work, however, alone will solve the problem.

DR. E. D. CHURCHILL.—This very beautiful work of Carter and Longacre has shown that physiologic compensation is not as it should be after the removal of one lung, although Rienhoff shows that the anatomic compensation is adequate.

Dr. Bremer, professor of anatomy of Harvard, has done a good deal of work on the postnatal growth of lungs in young animals. It occurred to us that the situation in the young animal might be different than it is in the adult animal. Dr. Tyson has removed one lung in kittens to study this point. Dr. Bremer has examined this material and can demonstrate in the young animal an actual growth of the remaining lung as a compensatory mechanism, in contrast with the adult, in which the compensation is, as Dr. Rienhoff brought out, by dilatation of the terminal respiratory units.

Dr. Jackson's paper was very interesting to me, because we have struggled with this group of tumors, and I have already purged myself of the mistake in reporting one of these cases as a removal of cancer of the lung by surgery.

Dr. Jackson spoke of the varying opinion of the pathologists, and their disagreement. You notice that Dr. Purdy Stout will not call them adenomas. He will not even call them tumors. The idea occurred to us that they might be vestigial structures of some type. I took our series of slides again to Dr. Bremer, an embryologist of the lung, and put them under the microscope and asked him what it was. He said, "That is fetal lung. Where does it come from?"

We went over our specimens, showing him exactly the localization in the bronchial tree. He referred me to some anatomic work, showing the frequent occurrence of vestigial lobes of the lung arising in this position in the tracheobronchial tree. Occasionally they even extend up into the neck or form mediastinal lobes. So we are following a trail that may lead to the exclusion of this group of so-called tumors from neoplasms entirely. They may very well be, if Dr. Bremer is correct, simple vestigial lobes of the lung, growing endobronchially, or deep within the structures of the bronchial wall.

DR. WILLIAM F. RIENHOFF, JR.—I want to thank Dr. Graham for his discussion, but I still am not sure that he is wrong and I am right.

In regard to Dr. Head's asking about bronchiectasis, we have had no evidence whatsoever of bronchiectasis developing in the remaining lung, nor have I seen it following partial lobectomy, in lobes in which there was no bronchiectasis before lobectomy.

THE FATE OF THE REMAINING LUNG TISSUE AFTER LOBECTOMY OR PNEUMONECTOMY*

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Boston, Mass.

THE technical difficulties encountered in the surgical removal of one or more lobes of a lung or of a whole lung have now been so well surmounted that the immediate results of the operation are no longer greatly feared. The end-results, however, in regard to the patient's expectation of regaining a normal metabolism are not so clear, since conflicting reports exist concerning the fate of the lung tissue remaining after the operation and its ability to carry on the full function of both intact lungs. In two recent articles dealing with this subject diametrically opposed views are presented. Hilber (1934) states that, in his operations on rats, an initial compensation for the loss of one or more lobes is accomplished by an increase in the level of the diaphragm, displacement of the heart and mediastinum, often accompanied by scoliosis convex to the opposite side, and by an increase in size of the remaining lung by simple distention of the alveoli, but that this stage is gradually replaced by true regeneration of normal lung tissue, accomplished by new growth, entailing an increase in the number of the respiratory units containing new alveoli of normal size and structure, and the remodeling of the bronchial tree. On the other hand, Rienhoff, Reichert and Heuer (1935) come to the opposite conclusion: "Compensatory changes in dogs consist of simple dilatation of the respiratory lobules or the definitive respiratory units made up of the bronchiolus respiratorius, the ductus alveolaris, the atria, the sacculi alveolares, and the alveoli. This dilatation comes in response to increased physiological demands and is of a compensatory nature. It is in no sense of the word an emphysema and there is no interruption or diminution of the elastic tissue or fusion of the alveoli to suggest pathological change in the lung parenchyma. There is no increase in the number of the bronchial trees or in their pattern, and apparently the blood vascular system, except for a possible dilatation, is unaffected. No evidence of a true hyperplasia or a hypertrophy was found." These changes refer to the end-result of the operation, not merely to the initial stage described by Hilber, for the dog particularly described by these authors had lived six months after a total left pneumonectomy, and the distended right lung had already filled the space of both thoracic cavities.

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Received for publication, July 30, 1936.

It is perhaps unfortunate that the phrase "in no sense of the word an emphysema" is used instead of "in the usual sense as used in pathology" (connoting changes in the elastic tissue, fusion of the alveoli, etc.), since vesicular or alveolar emphysema, as opposed to interstitial, is defined not infrequently as the condition of the lungs due to abnormal distention of the alveoli with air. Hilber uses the term with this meaning in describing the initial compensation. The intent of the two articles, however, is clear: one describes a preliminary distention followed by a true regeneration and the formation of new alveoli; the other considers the distention as the permanent result, denying the possibility of any regeneration. It is the purpose of this present paper to show that either of these results is possible, the determining factor being the capacity for further growth of the remaining lung in each individual case.

Normal growth, in mammals, is particularly inherent in the young. Examination of the literature with this point in mind is instructive. Haasler (1892), in a dog of ten weeks, found that the remaining right lung after six months filled the thorax and showed histologically normal structure, with alveoli of normal size and normal epithelium. "This is therefore a true hyperplasia, in Virchow's sense of the word." In adult animals this was not the case. Möllgaard and Rovsing (1910) recognized both possibilities, hyperplasia resulting only in young animals. Kawamura (1914) cites two cases in which the left lung was small, one in a woman of thirty years (a case of malformation of both lungs), the other in an individual whose age is not given; in both cases the right lung is described as normal, but in another similar case cited by him enlarged alveoli are reported. Perhaps in the last case the shrinkage of the lung may have occurred in adult life; while in the two former cases the lung was congenitally small. Knott (1934), in her report of a case of complete congenital absence of the right lung in an infant who died of bronchopneumonia at five weeks, describes the left lung as hyperplastic, "as in all hitherto described cases," with a slight increase in interstitial tissue and "perhaps" a noticeable increase in the size of the alveoli and infundibula. Hyperplastic regeneration of the remaining lung in young mammals has, then, as these few citations show, been often recognized, and in some cases the difference in the behavior in the adult has been stressed.

The normal lung after birth grows by the increase in the number of its alveoli, not by their increase in size. The normal kitten of three days or of three weeks and the adult cat all have alveoli of the same size and alveolar septums of the same thinness. In rabbits and some other animals which are born in a more fetal state there is a postnatal period in which the lungs are more cellular and the alveolar walls thicker, but this period is transitory. The numerical increase of alveoli is accomplished by the development of terminal buds from the angles

of the alveoli throughout the lung, in the form of minute tubular sprouts which expand into new alveoli. There are apparently no new buds from the bronchioles. The parietal alveoli of the respiratory bronchioles show no evidence of growth in the form of mitotic figures and represent the degenerating alveoli of the alveolar ducts which during development are constantly being converted into bronchioles by the downgrowth of the muscular layer. Thus as the tree lengthens distally the size of the individual lobules remains constant; their number increases and new bronchial branches are added.

The minute tubular sprouts mentioned were first noted by me in 1904 and have been described more fully in a later communication (1935). Two are shown in Fig. 1, from the normal lung of a rabbit

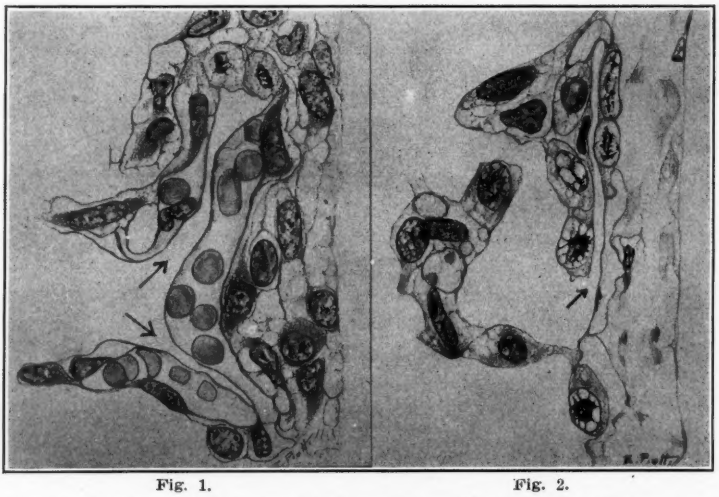

Fig. 1. Fig. 2.

Fig. 1.—Tubular sprouts, indicated by arrows, growing from an alveolus; formation of new alveoli. Rabbit lung, three days after birth.

Fig. 2.—Similar tubular sprout, showing growth in normal manner in remaining lung of kitten removed thirty-three days after total right pneumonectomy.

of three days. Unless studied in thin serial sections they would be thought to represent merely the local collapse of the alveolar wall, but the sections above and below show that except for these projections the alveolus in this area is smoothly rounded. The sprouts seem to be true projections from the alveolar wall, and their presence is taken to indicate the continuity of the alveolar epithelium, in spite of its close relations with the capillary endothelium. Da Fano (1912), however, regards them as rows of endothelial cells or actual capillaries which separate themselves from the wall of a vessel "in order to join each other after a short distance in such a way that a small space is formed between them." Hilber, whose article appeared while mine was in

press, also mentions these sprouts as indicating growth. It is interesting to note that his descriptive name is the counterpart of mine—"röhrenartig hervorspringende Spitzen," tubular sprouting tips. Their presence in a lung indicates that actual growth is in progress.

Through the kindness of my colleague, Professor E. D. Churchill, I was given one adult cat and one kitten of five weeks, both of which had survived total right pneumonectomy for more than a month. The remaining lung was fixed in each case by the same procedure that was adopted in my earlier work—the intratracheal administration, in the anesthetized animal with unopened chest, of large quantities of Bouin's fluid, accompanied by forceful movements of artificial respiration. After a few minutes of inaction, the chest was opened and the lung was found

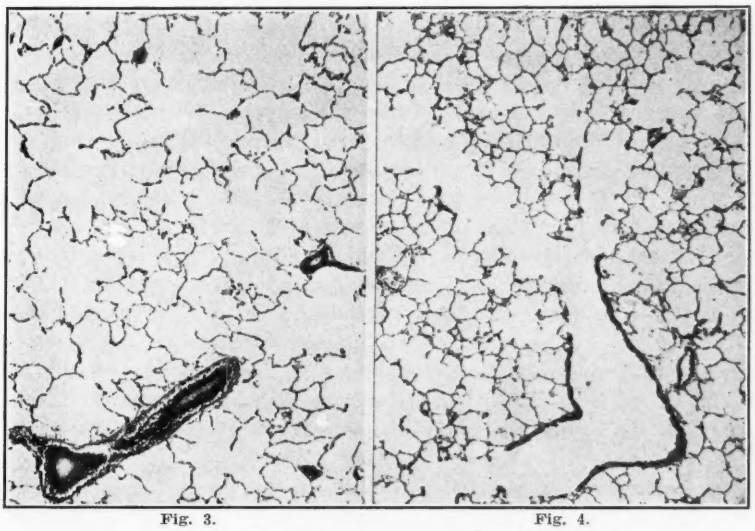

Fig. 3. Fig. 4.

Fig. 3.—Photograph of section of remaining lung of adult cat one month after right pneumonectomy; alveoli enlarged, arterial walls thickened.

Fig. 4.—Similar photograph of remaining lung of kitten thirty-three days after right pneumonectomy; alveoli and respiratory units of normal size. Figs. 3 and 4 are of the same magnification.

fixed in the position of rest, and could then be removed and immersed in the fluid. Other investigators have used other methods, such as first opening the chest or removing the lung and then distending it with the fixing fluid under known pressure. It seems to me of little import what method is employed provided that in any one set of experiments one method is adhered to, though accurate comparisons of data attained by different methods of fixation should not be attempted, since the size of the alveoli, the thickness of the septums, and other finer details may vary with the degree of distention. Pieces from various areas of both these lungs were sectioned serially at five microns. The adult remaining

lung, which was greatly enlarged, showed the typical picture of simple distention of the alveoli (Fig. 3); that of the kitten, though also much enlarged, appeared normal in alveolar size (Fig. 4).

In the adult remaining lung an additional change was noted, in that the arterial branches showed an increase in musculature. This characteristic was described by Hellin (1906) as a transient result of the sudden alteration of the pulmonary circulation, which later disappears as the system becomes adjusted to the new conditions. It is not evident in the remaining lung of the kitten. This may be due to the greater adaptability of the younger vessels.

A rough estimation of the average diameter of the alveoli as seen in any one section can be reached by computation from many counts of the number of septums present along random portions of the pleural border of many sections visible in a microscopic field of known actual diameter. Similar counts should be added of the septums bordering long stretches of bronchioles or vessels in the interior of the lung when these happen to be cut lengthwise in the sections. These figures will not represent the full average diameter of the alveoli, for in any one section many alveoli will be cut tangentially or through a narrow angle. Somewhat greater values would represent the true alveolar diameter. In material all treated in the same way such figures are comparable. For the cat the average was 0.095 mm. and for the operated kitten 0.058 mm. Similar figures for normal animals showed 0.06 mm. for kittens of three days and of three weeks, and for an adult cat, alike in all. Rienhoff and his coworkers also give such figures. "The average dimension through the greatest diameter of the alveolus, found in a count, varied from 125 to 140 micra in the abnormal or autopsy specimen [operated adult dog], and in the normal lung from 75 to 82 micra." The ratio is about the same as that in my figures.

An indication of the size of the whole respiratory unit or lobule was also obtained by measuring the greatest distance between the end of the cuboidal epithelium of the respiratory bronchiole and the fundus of the most direct of its alveolar sacs, selecting those most favorably cut in the serial sections, and here again the figures (0.7 mm. for the remaining cat lung, 0.4 mm. for the operated kitten and for normal animals) show that the operated cat had much larger lobules. It is obvious that the adult remaining lung had responded by increase in total bulk through enlargement of the individual alveoli and respiratory units already present, while the immature lung had attained a similar enlargement by the multiplication of its alveoli and the orderly rearrangement of its bronchial tree to supply normal lobules.

Further proof of the regenerative growth of the immature lung is found in the presence of the tubular sprouts, one of which is shown in Fig. 2. Here, as in Fig. 1, active growth is indicated by mitosis in one of the component cells. The sprouts are also found in the normal

lung of this age, but seem to be more numerous in the remaining lung, as was also noted by Da Fano. The increase, though almost impossible to measure because of the difficulty of recognizing these structures, may indicate the extent of the additional growth in this case above the normal growth at this age, also attested by the increased size of this lung.

One set of observations seems to stand out as definitely contradictory to the thesis so far elaborated; namely, that remaining lungs undergo permanent expansion in the adult, but in the young, on the contrary, after initial temporary expansion, they proceed to an orderly overgrowth of normal tissue. Hilber, whose paper has been cited as demonstrating true regeneration, used rats as his experimental animals and specifically states that he chose adult and in part even old individuals so that the regenerative changes should not be confused by those of the normal growth of youth. Donaldson (1924), however, by his careful compilation of the data concerning the rat, especially of the Wistar Institute strain, shows that in this animal growth is continuous even in the adult, for sexual maturity occurs at about two months, while body weight and the weight of the skeleton and of various organs are still increasing at 485 days, representing body weights of 326 grams for males and 234.7 grams for females. For the lungs in particular he finds (following Jackson) that the lung weight increases both actually and in proportion to body weight for a still longer period, up to a body weight of 450 grams. Donaldson, taking the lifespan for man and for rat as 90 years and 3 years respectively, considers that corresponding life periods are approximately equivalent: a rat of 450 grams would be well over 500 days in age, and therefore comparable to a man over forty. Beyond this period measurements were not taken, but his last few figures give no indication of any diminution in growth rate.

Increase in the weight need not imply increase in the size of an organ. The older lungs may contain a greater proportion of connective tissue or of inspired soot, but such changes are not apparent in the adult rat lung, nor are they noted by Hilber in his special studies of the regenerated adult lungs. That the normal adult rat lung has the opportunity for continued growth in size within the pleural cage is shown by the series of articles by Dawson dealing with the phenomenon of "lapsed" epiphyseal union in the rat. In one of these papers (1927) he finds that ossification and union of the heads of the ribs are only beginning in animals of 30 months, and in all the old rats examined cartilage plates were observed both in the ribs and in the sternum. This would permit continued growth of the pleural cavity to accommodate the enlarging lungs.

Later Dawson extended his observations to other strains of rats and (1935) to the mouse. Harman and Saffry (1934) state that in the guinea pig ossification is not complete in the bones of the fore-limb in

any of the animals examined by them, and it is well known that in this animal total growth continues long after puberty. It is probable that continued growth after maturity and "lapsed" epiphyseal union are characteristic of the rodent group. This may explain some of the conflicting data reported from experiments on lung extirpation in which rabbits have been used. The main point at issue in this present paper is that in these animals the lung may be considered as capable of growth long after maturity, and that thus in them the remaining lung after pneumonectomy should react by regeneration of normal alveoli and respiratory units, as in the case of immature lungs of other species. Hilber's results on rats should be classed with those reported on young animals.

CONCLUSIONS

The permanent result of lobectomy or pneumonectomy may be either a simple distention of the remaining lung tissue by dilatation of the alveoli and respiratory units, or a true regeneration by means of new growth of normal alveoli and respiratory units, marked by the presence of tubular sprouts indicative of normal growth.

Regeneration occurs in the young, dilatation in those whose lungs have ceased growing. This latter condition is usually found in the adult, but in the rat and probably in other rodents normal growth continues almost throughout life. In adults of these forms regeneration of the remaining lung is to be expected.

Dilatation of the alveoli would give only a little more respiratory surface than the original lung, only so much more as might be added by the lengthening of the alveolar walls. Physiologically the dilated lung might be at a disadvantage in that the air would not be so finely divided and would thus have a lower ratio of air surface to air bulk. This might be compensated by the increase in the vascular bed, brought about by the passage through the remaining lung tissue of all the blood from the right heart. Still the dilated condition can be regarded only as a makeshift, not as a complete recovery from the operation by regeneration of lung tissue.

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TOTAL PNEUMONECTOMY FOR CONGENITAL BRONCHIECTASIS

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ON APRIL 28, 1936, a boy twelve years old was operated on by me for a polycystic lung on the right side. Four months previously my assistant, Dr. Ivanissevich, had performed an intercostal drainage for a purulent collection in the lung. It was decided that after the intercostal drainage was healed an exploratory thoracotomy should be performed with the idea of possibly removing the entire lung, since it seemed to us that the condition was probably a congenital bronchiectasis involving the upper and middle lobes (Fig. 1). Before the operation, in accordance with our custom since 1919, we performed an artificial pneumothorax which, however, did not result in a complete collapse of the lung because of the presence of many adhesions involving the upper lobe (Fig. 2).

With ethylene narcosis we removed an anterior flap of the chest wall consisting of the second, third and fourth ribs of a length of about 10 cm. each. After entering the pleural cavity it was found that all the upper lobe and part of the middle lobe were involved and that many adhesions existed between the lung and the chest wall. Also it seemed impossible to preserve the lower lobe, and consequently a total pneumonectomy was decided upon. Accordingly, a Wertheim bent clamp was applied to the pedicle, and the lung was cut off with a stroke of the scalpel, leaving a little of the stump projecting outward from the clamp. A ligature with strong silk was applied, and the remaining stump was covered with a flap of posterior pleura. Since bleeding occurred from the thoracic wall at the site of the adhesions to the upper lobe, and since the protection of the stump was not regarded as entirely satisfactory, we decided to pack the pleural cavity with five large gauze compresses. The wound was closed leaving only a small opening through which the gauze pack emerged. The gauze was removed fifteen days after the operation. The postoperative course was normal. Although the wound is not yet completely healed, ninety days after the operation, the patient is healthy and feels perfectly well.

I think that packing the pleural cavity is a valuable means of combating an infection of the pleura, especially since we do not know of

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Received for publication, September 11, 1936.

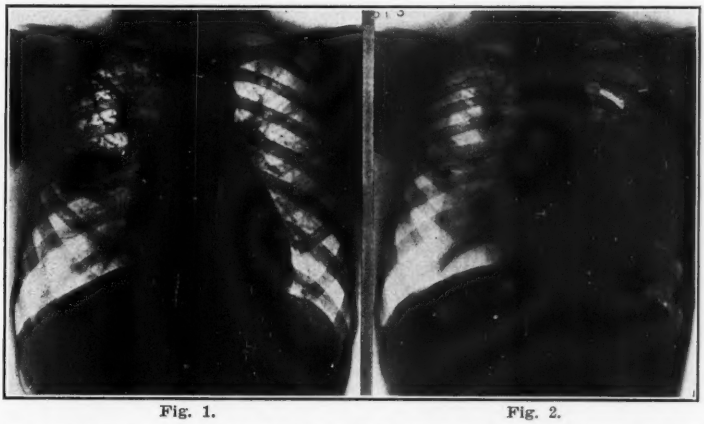

Fig. 1. Fig. 2.

Fig. 1.—X-ray film showing the filling of a large cavity in the right upper lobe with iodized oil.

Fig. 2.—X-ray film showing the previously induced pneumothorax and the adherent upper lobe.

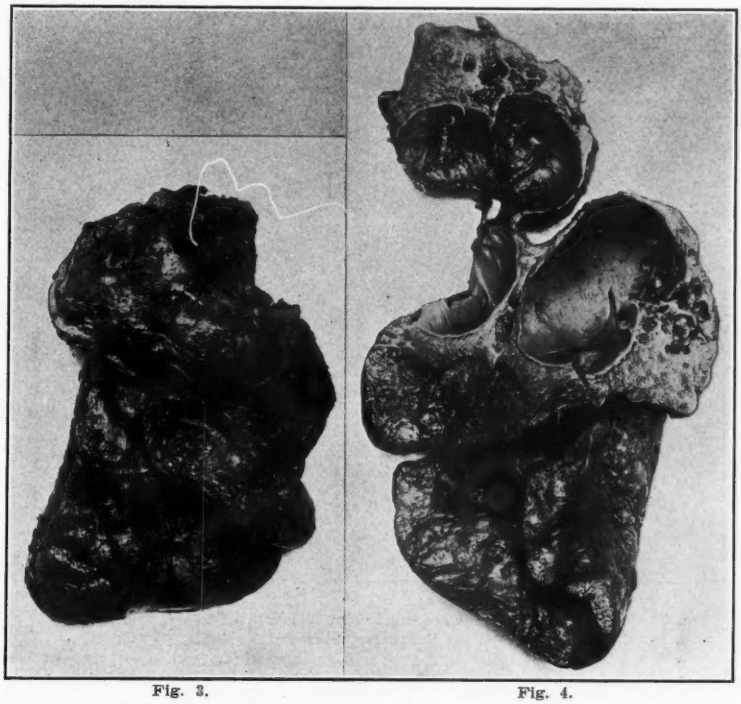

Fig. 3. Fig. 4.

Fig. 3.—Anterior view of the excised right lung.

Fig. 4.—Cut section of the upper lobe showing the large cysts.

Fig. 5. Fig. 6.

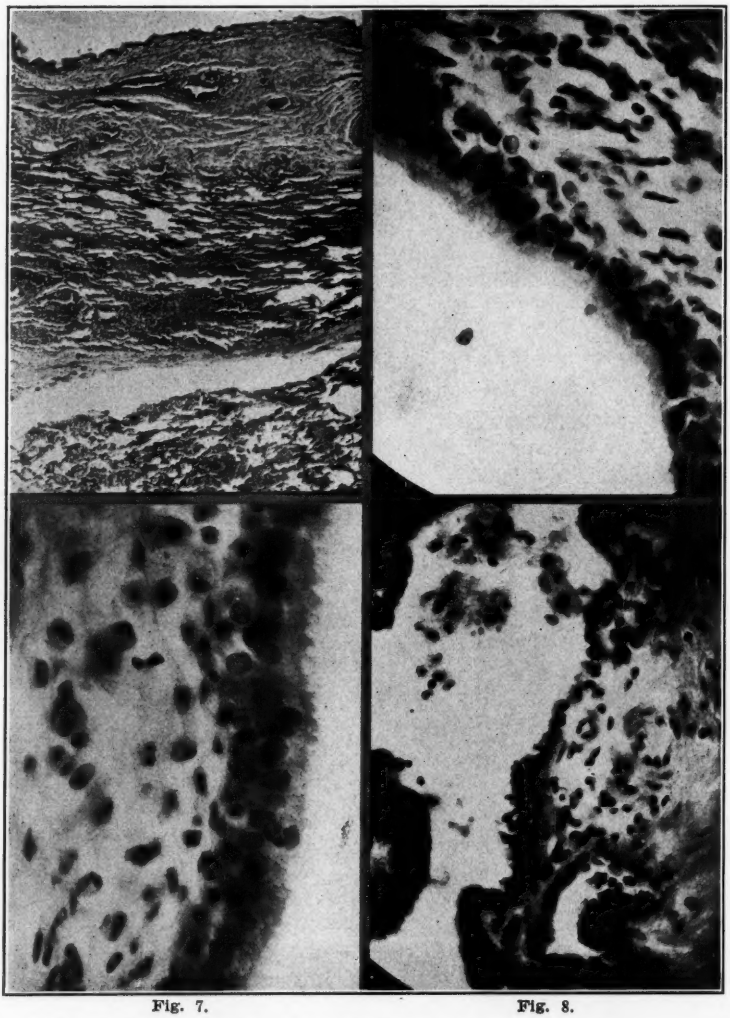

Fig. 7. Fig. 8.

Fig. 5.—Wall of large cavity surrounded by sclerotic tissue. (×12.)

Fig. 6.—Cylindrical epithelium lining the large cavity wall. (×650.)

Fig. 7.—Agglutinated ciliary processes in cylindrical epithelium of wall of large cavity. (×680.)

Fig. 8.—Cylindrical epithelium in a small cavity. (×280.)

Fig. 9. Fig. 10.

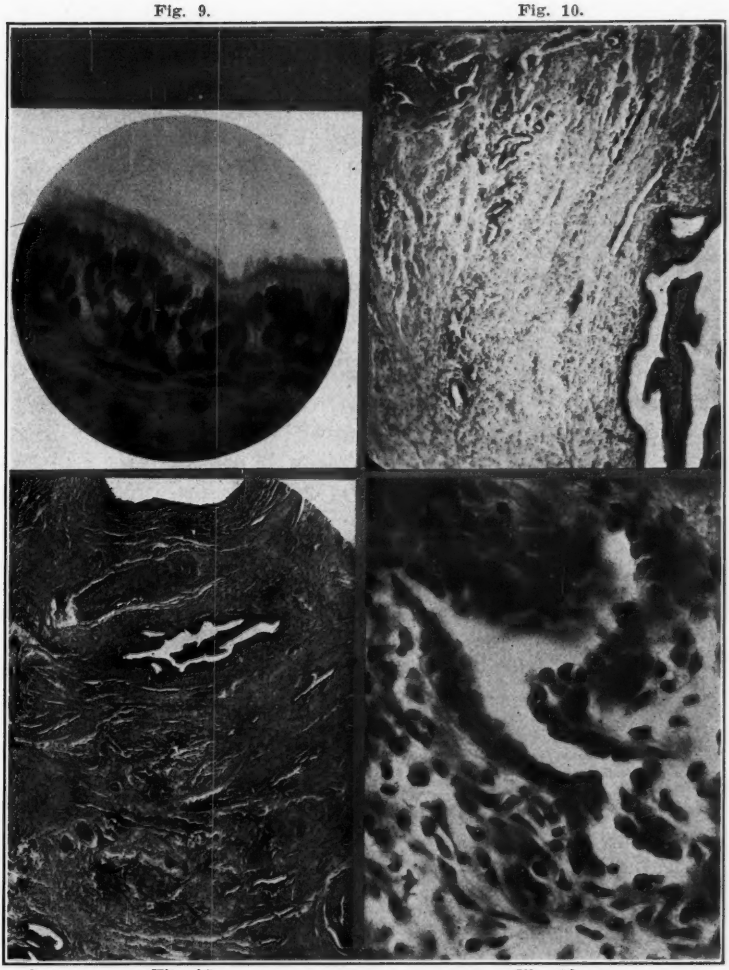

Fig. 11. Fig. 12.

Fig. 9.—Cylindrical epithelium with cilia from a small cavity. (×680.)

Fig. 10.—Small cavity surrounded by sclerotic tissue and including other structures resembling alveoli. (×20.)

Fig. 11.—Wall of a large cavity. In the surrounding sclerotic tissue there are smaller cavities. (×15.)

Fig. 12.—Alveolar cavity included in sclerotic mass with cuboidal epithelium.

reliable methods by which to avoid such an infection. When I removed the gauze packs fifteen days after the operation, the cavity was uniformly reddish and was covered with healthy granulation tissue. Neither the stump nor the silk could be seen. The silk ligature has not yet been extruded.

Fig. 3 illustrates the right lung which was excised. The upper lobe shows the pleura to be roughened and a soft air blister which did not crepitate under the fingers. A section (Fig. 4) shows many cavities, some of them reaching the size of an egg. Those in the middle lobe are not so large, but they communicate with each other like the holes in a sponge. The large cavities situated directly at the periphery of the upper lobe are covered with a very thick pleural wall. The interior of some of them contains a glistening lining, but most of them contain hemorrhage and exudate. The cavities are surrounded by hard sclerotic tissue which seems to be well vascularized. In only a few parts of the upper lobe is to be found tissue with the characteristics of normal adult lung tissue and that is atelectatic. The sclerotic tissue which surrounds the cavities in the upper lobe is continued by irregular strands into the middle lobe, but they do not reach the center of it. The rest of the middle lobe shows only a healed bronchitis with connective tissue thickening of the peribronchial layers.

Microscopically it is seen that the large cavities are lined with a single layer of cylindrical epithelium (Fig. 5) whose cells show variation in height due to a dilatation of the cysts. The epithelium seen in the photomicrograph is undoubtedly of bronchial type (Fig. 6) much like that found in an embryonic lung. It is possible to point out in some cells the existence of agglutinated ciliary processes (Fig. 7), an occurrence which confirms our suspicion of the bronchial type of epithelium. The small cavities in which the epithelium has not been much injured by exudation or by simple dilatation show cells of the inner layer characteristic of bronchial cells in respect to not only their individual morphology but also their location (Fig. 8). In some of them it is possible to see well-formed cilia and the characteristic basal cells as shown in Fig. 9. The sclerotic tissue surrounding the cavities is the site of an exudative infiltration occurring frequently as perivascular rings composed of small round cells, lymphocytes and plasma cells. Few polymorphonuclear cells are seen (Fig. 10). In the sclerotic mass there are found not only cavities lined by bronchial epithelium, but there are also small cavities with star shaped lumina clearly distinguished from the other large structures not only by their reduced size but also by their structure (Fig. 11). Each of them consists of a glandlike formation with an inner lining of a single layer of cuboidal epithelium identical with the embryonic alveolar epithelium of the lung (Fig. 12). There is a supporting young connective tissue rich

in fibroblastic cells and small cell infiltration. In the light of present information we accept those cavities as being embryonic alveoli in a condition of atelectasis. Among those alveoli and crossing them in all directions without any systematic disposition, strands of plain muscle cells are seen in great number alternating with broad collagen bands. In the middle lobe there is no pathologic evidence of actual disease; only peribronchial infiltration and sclerosis are found. The lower lobe is affected only by passive congestion.

Since the manuscript for this article was submitted for publication another patient has been operated upon successfully by the same method.

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MASS LIGATION OF THE PULMONARY HILUM WITH A SILVER BAND

An Experimental Study

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Robert Zollinger, M.D., Boston, Mass.

IN DEALING with inflammatory diseases of the lungs, lobectomy and pneumonectomy must as a rule be accomplished by a mass ligation of the hilum rather than by dissection and ligation of the individual structures. This mass ligature must be sufficiently tight to cause an ischemic necrosis if the lung is left in place to slough away, or to prevent hemorrhage if the lung is immediately excised. It is frequently difficult to secure a satisfactory mass ligation by the ordinary suture materials. To overcome this difficulty Carr[1] has devised a method of locking

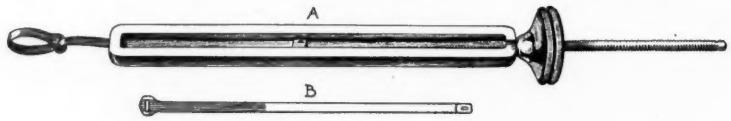

Fig. 1.

a cord snare in place by a metal key which is allowed to slough away with the lung. Archibald[2] and Bethune[3] have used a silver wire, twisted in place and left in situ after excision of the lung or lobe.

It occurred to one of us (R. Z.) that a mass ligation might conveniently be accomplished by a metal band* applied by the method worked out by Parham[4] for the fixation of fractures. After a number of trials a satisfactory band was devised of annealed silver 0.020 inch in thickness and 0.18 inch wide (Fig. 1). The distal third of the band was grooved longitudinally to insure against lateral slipping after application. The proximal end of the band was made double thickness for a quarter of an inch to prevent the eye, through which the pull is

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Received for publication, July 7, 1936.

*The use of a metal band in pulmonary surgery was first suggested by Halsted[5] who, in attempting to produce pulmonary emphysema and atelectasis in the dog, applied aluminum bands to the bronchi in such a way as to cause partial or complete occlusion. Heuer[6] used the same type of band to close the bronchus in performing total pneumonectomy in the dog. This was not applied as a mass ligature, however, for the vessels were ligated and cut separately. He tried this procedure in two dogs, one surviving and the other dying in four days of tension pneumothorax from a perforation in the bronchus proximal to the band.

exerted by the applicator, from tearing through. A length of five and one-half inches was sufficient to encircle the hilum conveniently.*

Using this band to secure mass ligation it was found that pneumonectomy or lobectomy in dogs could be accomplished with ease and rapidity.

METHOD

The dogs were anesthetized with morphine and intratracheal ether. The skin was prepared with soap and water, iodine and alcohol, and excluded from the wound with gauze pads. The chest was opened through the fifth interspace, the lung delivered and the hilum encircled by the silver band. No preparation of the hilum was necessary beyond releasing one or two of the fine connective tissue septums. The band was pulled tight, crushing the hilum down to a diameter of about 5 mm. There was no tendency for it to loosen when the applicator was withdrawn, and it was a simple matter to lock the band in place by bending it back upon itself. The surplus band was cut away with stout scissors. Clamps were placed distally, and the lung was excised between the band and the clamps leaving a stump about 5 mm. long distal to the band. The stump was cauterized with phenol and alcohol and the chest closed with pericostal sutures and silk to the muscle layers. The air was evacuated as completely as possible during closure by inflating the remaining lung.

RESULTS

Pneumonectomy was performed in sixteen dogs. In the first five of these, two bands were placed on the hilum which was severed and cauterized with phenol distal to the second band. Three of these dogs died of septic pleuritis four to ten days after operation. Two dogs survived, one being sacrificed nine months later, and the other dying of distemper three weeks after operation. It was thought likely that this high incidence of infection was caused by an infective focus provided by the long avascular stump, the central portion of which, between the two bands, could not be sterilized with phenol and therefore suppurated from the endobronchial organisms. In the remaining experiments, therefore, only the one band was used. There were no further infections except in the only two cases in which the stump was cauterized with the endothermy rather than phenol. The first of these two dogs died of septic pleuritis four days after operation, and the second died of tension pneumothorax on the seventh day. The band had been placed as high as possible on the hilum with the lung held out on tension. Autopsy showed that the bronchus had pulled itself out of the band from the tension resulting from this faulty application. This dog likewise showed purulent fluid in the pleural cavity.

As a result of these experiences, the procedure was finally modified as previously described. Only the one band was used; this was placed well out on the hilum about 2 cm. from the bifurcation of the trachea, and the stump was cauterized with phenol. Thirteen dogs were operated upon using this technic, left pneumonectomy being performed in seven, right pneumonectomy in two, and lobectomy in four. There were no infections in this group. The dogs were active, afebrile and eating well the morning after operation. All four of the lobectomy dogs survived and were later used for other studies. Only five of the nine pneumonectomy dogs survived, however, four dying of tension pneumothorax. The two dogs in which the right lung was removed died suddenly on the eleventh and fourteenth day after operation, and autopsy showed

*In the human being a length of about seven inches would be necessary to encircle the entire hilum.

a small leak in the bronchus just proximal to the band where it had eroded through. Two of the seven dogs in which the left lung was removed died on the seventeenth and twenty-eighth day after operation. Autopsy showed a similar erosion through the bronchus just proximal to the band. The five dogs which survived were sacrificed seven to ten months later. In four, the band was found in place, sealed over with a smooth film of connective tissue and pleura. The stump remained as a fibrous cord within the band. In the fifth dog roentgen ray examination five weeks after operation showed no trace of the band, and autopsy seven months later likewise showed the band to be missing. The pleural cavity was clean and the stump obliterated. Apparently the band had ulcerated into the bronchus and had been coughed up.

COMMENT

The high mortality from tension pneumothorax resulting from erosion of the bronchus proximal to the band clearly indicates that our procedure could not be employed in the one-stage closed operation in man. However, this would not contraindicate its use in the two-stage operation, or in the one-stage lobectomy as advocated by Brunn[7] and others where suction drainage is immediately instituted and where a temporary bronchial fistula is not an unusual or particularly serious complication. In all our experiments hemorrhage was completely and permanently controlled, and postmortem study showed no erosion of the band into the blood vessels. The vessels were found to be permanently occluded by pressure necrosis and repair as early as five or six days after application of the band. The bronchus, on the other hand, was potentially patent with fairly normal appearing mucosa for as long as two or three weeks after operation. After seven months, however, all the structures in the grip of the band were atrophied and replaced by a solid fibrous cord.

Our observations on the incidence of septic pleuritis lead us to differ with Heuer[6] who concluded that the bronchus contained no organisms and that attempts to sterilize the stump were needless. The high incidence of infection which seemed to emanate from an infected stump in the cases in which two bands were used was in striking contrast to the absence of infection where just one band was applied and the stump cauterized with phenol. Our experience, likewise, has led us to believe that phenol accomplishes the sterilization of the stump more efficiently than does the coagulating endothermy.

SUMMARY

A satisfactory mass ligation of the hilum for use in the two-stage lobectomy can be accomplished by means of a silver band. The vascular pedicle is well controlled, but the possibility of bronchial erosion and leakage would prevent the application of this method to the one-stage closed lobectomy or pneumonectomy.

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Twentieth Annual Meeting of the American Association for Thoracic Surgery

Dr. Hans Jacobaeus of Stockholm, Sweden, will be the guest of the Association at the meeting in Saranac Lake on May 31, June 1 and 2. He will discuss "bronchospirometry" and its use in determining the indication for thoracoplasty in cases of bilateral tuberculosis.

The headquarters of the Association for the meeting will be the Hotel Saranac. Dr. Edward S. Welles is chairman of the local committee on arrangements.

The Program Committee will welcome the submission of papers by nonmembers as well as by members. Titles and short, but comprehensive, abstracts must be in the hands of the Committee by March 1.

The published program will be mailed to members about May 1. Nonmembers desiring copies before the meeting may secure them by writing to the Secretary.